

AD-A035 045

GENERAL MOTORS CORP GOLETA CALIF DELCO ELECTRONICS DIV F/6 9/5
FREQUENCY CONVERTER PORTABLE, ALTERNATING CURRENT MULTIFREQUENC--ETC(U)
JAN 75 T CORRY DAAK02-72-C-0210
R75-3 NL

UNCLASSIFIED

1 OF 4
AD
A035 045



ADA 035045

R75-3 ✓
JANUARY 1975

B.S.
①

FINAL TECHNICAL REPORT
FREQUENCY CONVERTER ✓
PORTABLE, ALTERNATING CURRENT
MULTIFREQUENCY, 10 KW

VOLUME III

Contract CDRL Item A002
Contract No. DAAK02-72-C-0210 ✓

Submitted to
U.S. ARMY MOBILITY EQUIPMENT
Research and Development Center
Fort Belvoir, Virginia

RECEIVED
JAN 26 1977
REGULATORY

APPROVED FOR PUBLIC RELEASE, DISTRIBUTION
UNLIMITED



Delco Electronics ✓

General Motors Corporation
- Santa Barbara Operations
Santa Barbara, California

COPY AVAILABLE TO DDC DOES NOT
PERMIT FULLY LEGIBLE PRODUCTION

14 R75-3
11 JAN 1975

V1-V2 has
rept no R74-40
mic

12 229p.

10 T. /Corry

9 FINAL TECHNICAL REPORT

6 **FREQUENCY CONVERTER
PORTABLE, ALTERNATING CURRENT
MULTIFREQUENCY, 10 KW.**
VOLUME III.

Contract CDRL Item A002

Contract No. DAAK02-72-C-0210
15

Submitted to

U.S. ARMY MOBILITY EQUIPMENT
Research and Development Center
Fort Belvoir, Virginia

RECEIVED
JAN 26 1977
REG-111

APPROVED FOR PUBLIC RELEASE, DISTRIBUTION
UNLIMITED



Delco Electronics

General Motors Corporation
- Santa Barbara Operations
Santa Barbara, California

406 400

CONTENTS

<u>Section</u>		<u>Page</u>
I	Introduction	1
1.1	Objectives	1
1.2	Major Accomplishments	1
1.3	Statement of Work	2
1.4	Summary of Results	3
1.4.1	Results of Task a	3
1.4.2	Results of Task b	3
1.4.3	Results of Task c	3
1.4.4	Results of Task d	3
1.4.5	Results of Task e	4
1.4.6	Results of Task f	4
1.4.7	Results of Task g	4
II	Project Details	5
2.1	Description of New Inverter Subsystems	5
2.1.1	400 Hz Inverter	5
2.1.2	60 Hz Inverter	5
2.1.3	Memory Timing Circuit	10
2.2	Conclusions	11
2.3	Recommendations	11
III	Reference Publications	14

REVISION 101

WTIS ☒ White Section

WTS ☐ Buff Section

UNANNOUNCED

IDENTIFICATION

BY

DISTRIBUTION/AVAILABILITY CODES

CHG. APPL. REP/OF SPECIAL

A

SECTION I INTRODUCTION

1.1 OBJECTIVES

The initial phase of the project ~~(Item 0001)~~ was the development of a breadboard circuit capable of performing all the electrical functions of a three-phase frequency converter, as defined in Attachment No. 1 of the contract. After demonstration of three-phase performance, the work scope was extended ~~(Item 0003)~~ to further develop the breadboard circuits to produce 10 kW of single-phase power at 60 Hz or 400 Hz.

Concurrent with development of the 10 kW frequency converter, Delco developed improved step voltage commutation methods for a 100 kW frequency converter under MERDC Contract No. DAAK 02-72-C-0338. Since some circuit advances were applicable to the 10 kW frequency converter, the work scope was enlarged ~~(Item 0004)~~ to incorporate the new circuits into the breadboard.

After three-phase and single-phase performance was demonstrated, an additional investigation ~~(Item 0005)~~ was added to the work statement. This involved demonstration of 15 kVA three-phase and 10 kVA single-phase operation of the breadboard, study of voltage regulation methods for operating the frequency converter from utility power, and performance of regulation tests with a Delco-developed voltage regulation system.

Additional inverter circuit developments (Item 0006) made it possible to replace the transistor step commutation circuits with thyristor circuits. The results of the investigations and developments of Item 0006 are included in this volume of the contract final report.

1.2 MAJOR ACCOMPLISHMENTS

The inverter of Item 0006 weighs approximately twenty pounds less than the inverter of Item 0001 and produces 50% more power.

The following components, costing about \$1600, were removed from the inverter circuit:

- | | |
|----------------------|----------------------|
| 4 Power Transistors | 4 Power Zener Diodes |
| 4 Driver Transistors | 2 Power Diodes. |

The following components, costing about \$250, were added to the inverter circuit:

2 Thyristors	1 Transformer
2 Inductors	4 20mfd Capacitors.

Photographs showing the transition from the inverter of Item 0001 to the inverter of Item 0006 are shown in Figures 1 through 4.*

The inverter of Item 0006 comes much closer to meeting all performance requirements than the inverters of Items 0001 and 0005.

1.3 STATEMENT OF WORK

Modification P00008 amends the basic contract schedule to add Item 0006 as noted below:

"0006 The Contractor shall furnish all engineering, labor, tools, services, supplies, equipment and facilities to design, install, test and deliver improved performance, lower cost circuitry mounted in the 10 kW Frequency Converter furnished as CLIN 0001. This work effort shall include but not be limited to:

- a. Memory Circuit Redesign – Widen power center and reduce the number of steps in the waveform.
- b. Redesign Step Autotransformer.
- c. Design and install Thyristor-Capacitor Commutation Circuitry.
- d. Investigate and improve short circuit and 60 Hz, Single-Phase Performance.
- e. Reduce Overall Weight – Incorporate circuit design changes where appropriate.
- f. Perform Design Demonstration Performance Tests – Tests shall be in accordance with Attachment No. 3 and shall also include maximum power checks and tests necessary to enable a design extrapolation to 100 kW.
- g. Document all technical effort and data for inclusion in final technical report."

* Illustrations begin on page 26.

1.4 SUMMARY OF RESULTS

The Item No. 0006 inverter has been tested to a power level of 27 kVA compared with a maximum power of 20 kVA for the circuit that used step transistors. The maximum power of the Item No. 0006 inverter has not been measured thus far because of the limitations of the laboratory power source.

Compared to the previous design, the Item No. 0006 inverter has these characteristics:

- No power transistors, driver transistors, or Zener diodes
- Lower cost
- Higher power capability
- Higher reliability
- More commonality of power switch devices.

1.4.1 Results of Task a

A new waveform was designed with these characteristics: 110° wide power center, 10° wide steps, total harmonic content 5.6%. This waveform permitted the removal of one set of steps from the step forming autotransformer, resulting in the elimination of four thyristors. The new logic circuit uses read-only memories with a total cost of \$75 compared with \$800 for the previous logic circuit.

1.4.2 Results of Task b

A new step forming autotransformer was designed for the 110° power center waveform. This transformer was assembled with E-I laminations and will be less expensive to manufacture than the C-core type transformer previously used.

1.4.3 Results of Task c

Thyristor-capacitor commutation for the step circuits successfully replaced the transistor commutation step circuits.

1.4.4 Results of Task d

New power center thyristor commutation circuits have been developed in which the energy stored in the commutation capacitor is essentially constant and independent of inverter current and voltage. This circuit improves commutation for all possible short circuit

conditions at the inverter output. With the Item 0005 inverter, 60-Hertz, single-phase power was limited primarily by the step switching transistors. The thyristor step commutation circuit permits single-phase power outputs greater than 10 kVA.

1.4.5 Results of Task e

Replacing the step switching transistors with the thyristor step commutation circuit resulted in a total inverter weight reduction of approximately 20 pounds.

1.4.6 Results of Task f

Tests were performed in accordance with contract Attachment No. 3 and included maximum power checks and tests necessary to permit a design extrapolation to 100 kW. Maximum power tests up to 27 kVA were conducted at 60 Hz and 400 Hz, three phase. The performance tests indicate that all performance specifications can be met. However, verification of efficiency measurements should be made because of inherent errors in the method of measurement used. It is felt that the results of the measurements made during the investigation are conservative.

Inverter characteristics such as deviation factor and maximum short circuit current capability can be easily changed. Deviation factor is a function of input-output filter energy storage. Short circuit current capability is a function of commutation circuit energy storage.

1.4.7 Results of Task g

All technical data are documented in Appendix A.

SECTION II PROJECT DETAILS

2.1 DESCRIPTION OF NEW INVERTER SUBSYSTEMS

The technical effort of Item 0006 resulted in modifications of the inverter power switch assembly and the memory timing circuits.

2.1.1 400 Hz Inverter

Figure 5 is a schematic diagram of the Item 0006 400 Hz inverter circuit. This circuit operates on the principle of "power factor correction." The output filter capacitance value is large enough so that the inverter current leads the output voltage by more than 35 degrees for all rated load conditions. The development of this circuit is described in Volume I of this report.

The power center thyristor commutation energy is supplied by voltage source V_B as shown in Figure 5. In previous circuits part of the commutation energy was supplied by a winding on the step autotransformer. Making the power center thyristor commutation circuit independent of the step autotransformer improves commutation for non-symmetrical short circuit currents. Figures 6 through 8 are photographs that show the bottom, top, and side views of the Item 0006 inverter.

2.1.2 60 Hz Inverter

A schematic diagram of Item 0006 60 Hz inverter circuit is shown in Figure 9. The significant developments for the 60 Hz inverter are the step voltage commutation circuit and the commutation boost circuit. The thyristor step commutation circuit made it possible to eliminate starvation commutation transistors with resultant lower circuit cost and higher reliability. The commutation boost circuit supplies energy to turn off the step thyristors and the power center thyristors during short circuit conditions. This circuit also has the advantages of supplying constant commutation energy for all values of inverter input voltage or load. A side view of the 60 Hz inverter with the required output filter capacitors is shown in Figure 10.

2.1.2.1 Explanation of Step Commutation Circuit

Current is transferred from one voltage level to another by a two-step commutation sequence. Assume that in Figure 11, thyristors SCR2 and SCRa are conducting current to the load, that the transformer polarity is positive, and that capacitor C is charged as indicated. In order to transfer the load current to level 1, SCRb and SCR1 are gated on. The discharge of capacitor C reverse biases SCRa and turns it off. SCR2 is turned off by the reverse voltage ringup of capacitor C, which leaves it charged at the proper voltage polarity for the next step change to level 0. Load current continues to flow through SCR1 and SCRb.

The Item 0006 inverter generates two sets of step voltages which are defined as Y and X functions as illustrated in Figure 12. These functions have a fundamental frequency three times that of the inverter output voltages. The step widths and heights of the Y and X functions are derived from the 110° power center waveform described in the Memory Timing Section of this report. The required commutation capacitor voltage polarities to commute each step are also defined in Figure 12.

Figures 13a and 13d illustrate step voltage circuits that can generate Y and X voltage functions for all load voltage and current conditions defined in Tables I and II. Load currents must flow through either free commutation or auxiliary commutation circuits in accordance with the definitions of the Y and X voltage functions.

Operation of the auxiliary commutation double bus stepchanging circuit is illustrated in Figures 14 through 17.

Y Function

A portion of the Y function step forming circuit is shown in Figure 14a. On the left side of the step transformer is shown the free commutation step selector thyristors. On the right is shown the step selector thyristors that require an auxiliary commutation circuit. The right side thyristors are connected alternately to two separate busses (a) and (b). The auxiliary commutation circuit consists of thyristors SCRa and SCRb and capacitor C. Capacitor C is charged as indicated and load current is flowing through thyristors SCR1 and SCRa.

Y FUNCTION	STEP VOLTAGE & CURRENT	
STEP TRANSFORMER VOLTAGE POLARITY	IN-PHASE	OUT-OF-PHASE
+	AUX. COMM. REQUIRED	FREE COMMUTATION
-	FREE COMMUTATION	AUX. COMM. REQUIRED

Table I. Methods of Commutation for Steps Formed by the Y Function

X FUNCTION	STEP VOLTAGE & CURRENT	
STEP TRANSFORMER VOLTAGE POLARITY	IN-PHASE	OUT-OF-PHASE
+	FREE COMMUTATION	AUX. COMM. REQUIRED
-	AUX. COMM. REQUIRED	FREE COMMUTATION

Table II. Methods of Commutation for Steps Formed by the X Function

Turning on SCRB causes capacitor C to discharge and reverse biases SCRa (see Figure 14b). Load current then transfers from bus (a) to bus (b). The current of capacitor C takes three paths: it supplies load current, it forces current to flow through the non-conducting thyristor of step 1 during resonant discharge, and it forces reverse current to flow through SCRa during the junction recovery interval. At this time the capacitor is in series with the load.

(See Figure 14c.) At this time SCRa is off. SCR0 thyristors are triggered on causing capacitor C to be clamped across voltage source v_{step} and to resonant charge through a current path that flows through SCR1, SCRB, and SCR0. Capacitor C charges to a voltage Kv_{step} . K is a function of the Q of the resonant charge circuit and a function of load current and must be greater than unity. When the capacitor is fully charged it reverse biases SCR1 causing it to turn off. The capacitor now has a sufficient energy with the proper voltage polarity to commutate the next voltage step. Load current now proceeds to flow through SCR0 and SCRB, as shown in Figure 14d.

Figure 18a shows gate trigger timing for SCR1, SCR0, SCRa, and SCRB during the commutation sequence illustrated in Figure 14. The time relationship between the turn-on of SCRB gate and the removal of gate drive from SCR1 is defined as $\Delta\mu\text{sec}$. For the Item 0006 60 Hz inverter Δ equals 35 μsec .

Figures 15 and 16 illustrate transfer of current from one voltage level to another for all other Y and X function step voltage and current conditions. The same step commutation principles apply for all these cases as for Figure 14.

2.1.2.2 Explanation of Commutation Boost Circuit

The thyristor reverse voltage step commutation circuit provides the basic mechanism for turning off the step thyristors. Commutation capacitor energy sources are the step voltage taps of the autotransformer. Hence commutation energy varies with

- 1) The dc voltage applied to the inverter
- 2) The step voltage magnitude
- 3) The inverter load current.

When commutation energy is obtained only from the step transformer voltage taps the inverter cannot function with short circuit loads and cannot start with large loads.

A commutation circuit is required in which the energy stored in the commutation capacitor is essentially constant and independent of inverter load or input voltage. The commutation boost circuit performs this function.

Figure 19a is a schematic diagram of the basic step voltage commutation circuit. Required is a source of commutation voltage that is available for each step commutation cycle at the proper polarity. The energy transferred during each commutation cycle should be constant. These requirements are met by the circuit of Figure 19b that shows the energy source circuit connected to the step commutation circuit. These circuits operate as synchronous twin resonant loops with a common inductor L_1 . Since the Y and X voltage steps for the 110° wide power center waveform used in the inverter change at the same time, both left and right steps are commutated with energy from the same boost voltage circuit.

Figure 20 shows the double resonant circuits in equivalent circuit form. The instant that thyristors B and R_{SB} are turned on the voltages of capacitors C_B and C_C add to provide a fast rise commutation current. Both capacitors discharge through the step thyristor commutation loop. Capacitor C_C charges to a voltage determined by the boost voltage V_B . Energy contributed by the step voltages or load current that exceeds $1/2 C_C \cdot K \cdot V_B^2$ is transferred via voltage developed across inductor L_1 and is subtracted from the energy supplied by the boost circuit.

Figure 21 shows the important voltage and current waveshapes in the step commutation and boost voltage circuits.

Equivalent commutation circuits before and during the commutation sequence are illustrated in Figures 22a and 22b. The complete step commutation circuit for the Y and X step circuits is shown in the schematic diagram of Figure 23. Inductors L_2 are wound on a common permalloy core to couple energy from one step commutation circuit to the other. This energy coupling assures equal commutation currents for both step circuits by compensating for slight differences in circuit resistances and Q .

2.1.2.3 Power Center Commutation C.T. Transformer

Figures 24 and 25 are schematic diagrams of a power center thyristor commutation circuit loop. The difference between the two diagrams is the current transfer (C.T.) transformer

In Figure 24. The C.T. transformer is an autotransformer with a turns ratio of 1:5. The transformer action reduces current flow in the power center thyristor bypass diode and consequently reduces the maximum current flow in the commutation capacitor C_C . Photographs of bypass diode current, capacitor current, and reverse commutation voltages are also shown in Figures 24 and 25. Use of the C.T. transformer reduces bypass diode current from 95 amperes to about 45 amperes at a load of 16 kW, PF = 0.8, as illustrated in the current waveform photographs.

2.1.3 Memory Timing Circuit

The gate trigger time for each thyristor in the inverter schematic circuits of Figures 5 and 9 is controlled by the output of a read-only memory circuit. Five 256 bit (32 x 8) memory chips are programmed on the basis of the computer optimized waveform defined by the drawing of Figure 26. This waveform has the following characteristics: the power center is 110° wide, each step is equal and 10° wide, there is a 10° wide zero dwell time. The total harmonic content (excluding triplens) to the 250th harmonic is 5.6%. The center step frequency is the 36th harmonic. The non-triplen harmonics greater than 1% are the 7th, 35th and 37th. Figure 27 is a chart showing the magnitudes of all non-triplen harmonics up to the 41st. Step voltage relationships between two phases are shown in Figure 28. The third step on the left and right sides of the power center are on simultaneously. Step changes on the left and right sides are made synchronously at a 10° step rate.

The waveform design for the three phase format is illustrated in Figure 29. This three phase waveform is used to design the inverter master timing chart of Figure 30. Each thyristor switch in the inverter circuit is designated on the left and the sequence of gate trigger signals are shown as a function of waveform degrees up to 365 degrees.

Information on the timing chart is utilized to organize the memory timing circuit in the block diagram of Figure 31. Sets of thyristors are assigned to specific programmable read-only memory chips; each memory is controlled and synchronized by appropriate counter and delay circuits.

The memory timing circuit is constructed with five volt, medium power TTL integrated circuits and programmable read-only memories. The output of a 3.456 MHz crystal oscillator is divided to produce a clock frequency of 8.64 kHz for 60 Hz operation or

57.6 kHz for 400 Hz operation as shown in the schematic diagram of Figure 32a. Clock pulses are fed into counters (Figure 32b) which address the read-only memories that synchronously output thyristor gate drive signals. Figure 33 is a photograph of the complete memory timing circuit.

Photographs of unfiltered voltage outputs for the inverter at 60 Hz operation are shown in Figures 34 through 38. Measurements of total harmonic content and individual harmonics of the inverter output voltages are listed in Table III and can be compared to the computer-calculated harmonics tabulated in the last column. Note: there is a very close correspondence between the computer and measured harmonic content values.

Comparisons of the individual harmonics for the waveforms of the inverters of Item 0005, Item 0006, and a new MERDC-designed waveform can be made from the tabulations of Table IV. The new waveform will be considered in future inverter designs because of the lower magnitudes of the 5th and 7th harmonics.

2.2 CONCLUSIONS

It has been demonstrated that power transistor step commutation circuits can be replaced by *thyristor commutation circuits*. Consequently, the power ratings of power center inverters are no longer limited by transistor current ratings. It appears that practical inverter power ratings of 100 kW can be achieved.

All tasks of Item 0006 were completed. A new 110° wide power center waveform was demonstrated. New power center thyristor commutation circuits were developed. A new step autotransformer using E-I laminations was fabricated and tested.

Tests were performed in accordance with contract Attachment No. 3 and included maximum power checks and tests necessary to enable design extrapolation to 100 kW. The performance tests tabulated in Appendix A indicate that all performance specifications can be met. However, verification of efficiency measurements should be made.

2.3 RECOMMENDATIONS

Additional development work in the following areas will lead to either lower circuit cost or to improved output waveform quality.

- Triplen attenuator design
- Input-output filter design
- Simplification or elimination of T_c^+ , T_c^- circuit.

HARMONIC NUMBER	FREQUENCY Hz	PERCENT OF FUNDAMENTAL		
		MEASURED* L-T-N	MEASURED* L-T-L	COMPUTED L-T-N
1	60	100.0	100.0	100.0
3	180	0.1	-	18.03
5	300	0.8	0.8	0.98
7	420	1.5	1.5	1.46
9	540	-	-	3.24
11	660	0.8	0.8	0.96
13	780	0.45	0.44	0.21
15	900	-	-	1.17
17	1020	0.87	0.87	0.65
19	1140	0.58	0.60	0.54
21	1260	-	-	0.86
23	1380	0.40	0.40	0.16
25	1500	0.37	0.36	0.43
29	1740	0.30	0.30	0.15
31	1860	-	0.1	0.12
33	1980	-	-	1.63
35	2100	3.0	3.0	2.88
37	2220	2.5	2.6	2.71
39	2340	-	-	1.37
41	2460	-	-	0.10

* Measurements made at output of triplen attenuator. Load = 11 kW,
PF = 1.0. 1 MFD Cap. L-T-N. Measured THD = 5.3%. Computer
Designed waveform THD = 5.6%.

Table III. 110° Wide Power Center, 10° Wide Step Waveform

	Item No. 0005 Waveform	Item No. 0006 Waveform	MERDC Waveform
Power Center Width	99°	110°	103.7
Step Width	9°	10°	10.9
No L-N Voltage Levels	6	5	5
Harmonic Distortion (Excluding Triplens)	4.2%	5.6%	5.0%
Harmonic	Voltage as % of Fundamental	Voltage as % of Fundamental	Voltage as % of Fundamental
1	100.0	100.0	100.00
3	16.2	18.03	16.30
5	0.19	0.98	0.15
7	0.61	1.46	0.87
9	1.06	3.24	1.04
11	0.65	0.96	0.85
13	0.51	0.21	0.51
15	0.40	1.17	0.70
17	0.36	0.65	0.24
19	0.33	0.54	0.61
21	0.27	0.86	0.07
23	0.30	0.16	0.54
25	0.22	0.43	0.07
27	0.27	0.15	0.29
29	0.22	0.35	0.69
31	0.34	0.12	2.49
33	0.11	1.63	3.28
35	0.01	2.88	2.25
37	1.28	2.71	0.58
39	2.59	1.37	0.20
41	2.45	0.10	0.03
43	1.10	0.22	0.29
45	0.02	0.08	0.04
47	0.07	0.22	0.24
49	0.21	0.07	0.04
51	0.12	0.34	0.20
53	0.13	0.19	0.13
55	0.09	0.19	0.16
57	0.12	0.30	0.17
59	0.09	0.05	0.10
61	0.10	0.16	0.00
63	0.09	0.05	

Table IV. Comparison of Harmonic Distribution for
Three Waveform Designs

SECTION III
REFERENCE PUBLICATIONS

- F. C. Schwarz. "Switch Modulation Techniques in AC to DC Power Supplies." 16th Power Sources Conference
- F. Lawn. "Static Inverters Using SCR with Pulsewidth Control." 17th Power Sources Conference
- F. C. Schwarz. "Switch Modulation Techniques in AC to DC Power Supplies." Part II, 17th Power Sources Conference
- S. J. Lindena. "The Current-Fed Inverter." 20th Annual Power Sources Conference
- B. K. Bose, J. R. Killough. "A Thyristor DC-DC Converter with Auxiliary Transistors Controlling On-Time." IEEE 1973 Industry Applications Meeting
- J. R. Taylor, J. A. Sunda. "Suppressing Harmonics Generated by Thyristor-Controlled Circuitry." Electronic Engineering, August 1971
- E. M. Perrin, E. T. Schonholzer. "Fundamental Operation of Rectifiers with Thyristor AC Power Control." IAS Seventh Annual Power Conversion Conference, 1972
- E. Muller, F. Ricke. "Undershoot Control Techniques and Their Influence on Inverter Output Voltage." Brown-Boveri Review 1-73
- E. Chiesa, P. Toso. "SCR's Control Tapped Autotransformer." Control Engineering, January 1964
- D. L. Cronin. "Research and Development Technical Report ECOM - 0245-F." Final Report, June 1970 to December 1970. TRW Systems Group, Redondo Beach, Ca. 90278
- R. Youn. "High Frequency SCR Inverter: A DC Regulator for Computer Power Supplies." IAS Seventh Annual Power Conversion Conference, 1972
- E. T. Calkin, B. H. Hamilton. "A Conceptually New Approach For Regulated DC-to-DC Converters Employing Transistor Switches and Pulse Width Control." IAS Seventh Annual Power Conversion Conference, 1972

- E. T. Calkin, B. H. Hamilton. "Circuit Techniques For Improving The Switching Loci of Transistor Switches in Switching Regulators." IAS Seventh Annual Power Conversion Conference, 1972
- W. Hirschberg. "High-Power Switching Regulator Achieves 75% Efficiency." Electronic Products Magazine, March 19, 1973
- F. Heath. "The Switching Regulator Power Supply." Electronics World, October 1971
- E. R. Hnatek. "Cut Noise In Switching Regulator." Electronic Design, October 28, 1971
- R. J. Heaver. "A 20k Hz, 1kW Line Operated Inverter." Motorola Application Note AN-588.
- R. H. Okada. "Choosing an Approach to Switching Power Supplies." Electronic Products Magazine, April 15, 1974
- T. Wolpert. "Uninterruptible Power Supply for Critical AC Loads - A New Approach." IAS Eighth Annual Power Conversion Conference, 1973
- R. Zielke. "A 50 mW Thyristor-Controlled Power Converter." IAS Eighth Annual Power Conversion Conference, 1973
- H. Winograd, J. B. Rice. "Conversion of Electric Power." Standard Handbook for Electrical Engineers, Tenth Edition pp. 12-2 to 12-51
- R. W. Miller, R. Leeman. "Voltage Profiles for a Twelve-Phase Rectifier System - Part 1 - Fixed Load." IAS Eighth Annual Power Conversion Conference, 1973
- J. H. Galloway. "Harmonic Line Currents In Large Thyristor Six-Pulse Converters." IAS Eighth Annual Power Conversion Conference, 1973
- A. Yair, et al. "Bridge Rectifiers With Double and Multiple Supply." Proc. IEE, Vol. 116, No. 5, May 1969
- W. N. Cheung. "Frequency Response of AC-DC Converter with Constant Current Control." Proc. IEE, Vol 118, No. 9, September 1971
- H. Zander. "Self-Commutated Rectifier to Improve Line Conditions." Proc. IEE, Vol. 120, No. 9, September 1973

L. L. Freris. "Multigroup Converters with Series A.C. Connection." Proc. IEE, Vol. 118, No. 9, September 1971

T. Gilsig. "An Interconnected AC Filter for HVDC Converters." IEEE Transactions on Power Apparatus and Systems, March 1970

A. G. Phadke. "Generation of Abnormal Harmonics In High-Voltage AC-DC Power Systems." IEEE Transactions on Power Apparatus and Systems, March 1968

N. G. Hingorani, P. Chadwick. "A New Constant Extinction Angle Control for AC/DC/AC Static Inverters." IEEE Transactions on Power Apparatus and Systems, Vol. PAS-87, No. 3, March 1968

J. Reeve, J. Baron, P. Krishnayya. "A General Approach to Harmonic Current Generation by HVDC Converters." IEEE Transactions on Power Apparatus and Systems, Vol. PAS-88, No. 7, July 1969

R. Smith. "Harmonic Voltages in the Outputs of Controlled Rectifier Circuits." Electronic Engineering, December 1964

B. M. Bird. "Harmonic Reduction in Multiplex Converters by Triple-Frequency Injection." Proc. IEE, Vol. 117, No. 10, Oct. 1970

H. A. Gauper, J. D. Harnden, A. M. McQuarrie. "Power Supply Aspects of Semiconductor Equipment." IEEE Spectrum, October 1971

P. R. Ridler, F. Rhod. "Analysis of Single-Phase Capacitor-Input Rectifier Circuits." Proc. IEE, 1970

Handbook for the Calculation of Current and Voltage Harmonics on Three-Phase Ship-board Power Distribution Systems Due to Controlled Static Power Supplies. MPR-250. MPR Associates, Inc. NSEC Contract N00151-70-C-0879

S. Aoki, J. Hasegawa. "Some Regulated Power Supply Apparatus Using Morgan Circuit." Intermag Conference, 1964

H. S. Patel, R. G. Hoft. "Generalized Techniques of Harmonic Elimination and Voltage Control in Thyristor Inverters: Part 1 - Harmonic Elimination." IAS Seventh Annual Power Conversion Conference, 1972

- E. Relation, I. Winpisinger, J. Mitchell. "Uninterruptable Power System Using an Improved Magnetic Voltage Stabilizer." IEEE 1973 Industry Applications Meeting
- W. J. Bonwick, V. H. Jones. "Rectifier - Loaded Synchronous Generators with Damper Windings." Proc. IEE, Vol. 120, No. 6, June 1973
- D. B. Giesner, J. Arrillagra. "Behavior of HVDC Links Under Unbalanced A. C. - Fault Conditions." Proc. IEE, Vol. 119, No. 2, Feb. 1972
- A. Ametani. "Generalized Method of Harmonic Reduction in AC - DC Converters by Harmonic Current Injection." Proc. IEE, Vol. 119, No. 7, July 1972
- W. J. Bonwick, V. H. Jones. "Performance of a Synchronous Generator with a Bridge Rectifier." Proc. IEE, Vol. 119, No. 9, Sept. 1972
- H. H. Ho. "Sinewave Thyristor Parallel Inverter with Improved Commutation." Proc IEE, Vol. 113, No. 12, Dec. 1966
- S. Williams, I. R. Smith. "Fast Digital Computation of Three-Phase Thyristor Bridge Circuits." Proc. IEE, Vol. 120, No. 7, July 1973
- M. Hancock. "Rectifier Action with Constant Load Voltage: Infinite - Capacitance Condition." Proc. IEE, Vol. 120, No. 12, Dec. 1973
- B. J. Kabriel. "High Speed Three-Phase Thyristor Converter with Several Unusual Features." Proc. IEE, Vol. 114, No. 1, Jan. 1967
- R. J. Bland. "Factors Affecting the Operation of a Phase-Controlled Cycloconverter." Proc. IEE, Vol. 114, No. 12, December 1967
- J. D. Ainsworth. "Harmonic Instability Between Controlled Static Converters and A. C. Networks." Proc. IEE, Vol. 114, No. 7, July 1967
- R. J. Haver. "A 20kHz, 1kW Line Operated Inverter." Motorola Application Note AN-588.
- W. V. Peterson, R. J. Resch. "5kW Pulse Width Modulated Static Inverter." TRW Report ER-6809, NASA-CR-54872, Contract NAS 3-6475

A. D. Schoenfeld, Y. Yu. "ASDTIC Control and Standardized Interface Circuits Applied to Buck, Parallel and Buck-Boost DC-to-DC Power Converters." TRW Systems Report 21083-6001-RU-00, NASA CR-121106, Contract NAS 3-14392.

J. J. Biess, A. D. Schoenfeld, E. Cohen. "Power Porcessor for a 20 CM Ion Thruster." TRW Systems Report 20384-6002-RU-00, NASA CR-121160, Contract NAS 3-14383.

R. G. Klimo, et al. "Optimization Study of High Power Static Inverters and Converters." TRW Inc. Report TRW-ER-6586, NASA CR-54186, Contract NAS 3-2785

F. G. Spreadbury. Electric Rectification. D. Van Nostrand Co. Inc, 1962

Y. Yu, J. Biess, "Some Design Aspects Concerning Input Filters for DC-DC Converters," 1971 PCSC Record.

R.E. Morgan, "Bridge-Chopper Inverter for 400 Hz Sine Wave Power," IEEE Transactions on Aerospace, Volume 2, Number 2, April 1964.

A.G. Birchenough, F. Gourash, "Design and Performance Analysis of a Medium-Power DC-DC Converter," NASA TN D-5643.

F. Gourash, A.G. Birchenough, "Design Analysis and Performance of a 2.5 kVA Pulse-Width-Modulated Static Inverter," NASA TN D-5586.

D.L. Plette, H.G. Carlson, "Performance of a Variable Speed Constant Frequency Electrical System," IEEE Transactions on Aerospace, Vol. 2, No. 2, April 1964.

D.J. Hucker, "Comparison of Aircraft Electrical Systems to Supply Variable Frequency and 5 kVA Constant Frequency," IEEE Transactions on Aerospace Vol. 2, No. 2, April 1964.

T.M. Heinrich, A. Kernick, "Controlled Current Feedback in a Static Inverter with Neutrolization of Harmonics," IEEE Transactions on Aerospace Vol. 2, No. 2, April 1964

A.J. Humphrey, "Inverter Commutation Circuits," IEEE Transactions on Industry and General Applications, Vol. 1GA-4, No. 1, Jan 1968.

F. F. Mayda, "Design of High Frequency Thyristor Chopper Circuits," Electronic Engineering, Feb. 1970

J. P. Vergely, V. Glover, "Low-Power Solid State Inverters for Space Applications," WESCON 1966.

T. A. Finger, "Parametric Transformer Converts Single Phase to Three Phase," EDN September 1969.

M. A. Geyer, A. Kernick, "Time Optimal Response Control of a Two-Pole Single-Phase Inverter," PCSC Record 1971.

R. Feinberg, W. Y. Chen, "Commutation Phenomena in a Static Power Conditioner," Proc. IEE, Vol. III, No. 1, January 1964.

R. Feinberg, W. Y. Chen, "Commutation Reactance of the Transformer in a Static Power Converter," Proc. IEEE Vol. III, No. 1, January 1964.

E. T. Powner, D. H. Green, "Digital Waveform Synthesis" Electronic Engineering, August 1968.

P. D. Corey, "Methods for Optimizing the Waveform of Stepped-Wave Static Inverters," AIEE Conference Paper 62-1147.

P. D. Corey, "Design and Performance of a 20 kVA Ground Support Static Frequency Changer," IEEE Transactions on Aerospace-Support Conference Procedures, 1963.

L. J. Lawson, "Fuel Cell Conversion by the AC Link Type Static Inverter," IEEE Transactions on Aerospace and Electronic Systems, Vol. AES-2-No. 4, 1966.

E. Salters, "A High Power DC-AC Inverter with Sinusoidal Output," Electronic Engineering, September 1961.

K. Y. G. Li, "New Three-Phase Inverter," Proc. IEE Vol. III No. 11, November 1968.

A. Kernick, J. L. Roof, "Static Inverter with Neutralization of Harmonics," AIEE Aerospace Transportation Conference, May 1962.

C.W. Flairty, "A 50 kVA Adjustable-Frequency 24-Phase Controlled Rectifier Inverter," IEE Transactions on Industrial Electronics, May 1962.

N. Mapham, "An SCR Inverter with Good Regulation and Sine-Wave Output," IEEE Transactions on Industry and General Application IGA-3, No. 2, March 1967.

J.W. Ianniello, "Symmetry Correction for a Free Running Transistor Inverter," IEEE Transactions on Industry and General Applications, Vol. IGA-5, No. 1, January 1969.

C.G. House, "Arbitrary Waveform Generator," U.S. Patent No. 2,920,217.

T. Kobayashi, "Power Supply Filter for Noise Suppression," U.S. Patent No. 3,683,271.

T.M. Heinrich, "Static Inverter Wherein a Plurality of Square Waves are so Summed as to Produce a Sinusoidal Output Wave," U.S. Patent No. 3,491,282.

J.L. Jensen, "Electrical Apparatus," U.S. Patent No. 2,906,896.

L.J. Stratton, "Alternating Current Generating System" U.S. Patent No. 2,995,696.

D.E. Ruch, "Converter Circuit Employing Pulse Width Modulation," U.S. Patent No. 3,297,936.

D.L. Cronin, "Electronic Three-Phase Wave Generator," U.S. Patent No. 2,916,687.

L.R. Peaslee, "System for Providing a Range of Determinate Frequencies from a Variable Speed Source," U.S. Patent No. RE 26,237.

J.M. Hunt, "Linear DC to AC Converter," U.S. Patent No. 3,324,376.

R.D. Jessee, "Controlled Frequency Alternating Current System" U.S. Patent No. 3,170,107.

R.D. Jessee, "Constant Frequency Alternating Current System" U.S. Patent No. 3,178,630.

D.L. Lafuze, "Cycloconverter Power Circuits," U.S. Patent No. 3,431,483.

J.A. Ross, "High Power Synthetic Waveform Generator," U.S. Patent No. 3,100,851.

F.D. Kaiser, "Electric Power Translation System," U.S. Patent No. 2,986,691.

L.H. Walker, "Ring Counter Tube Inverter with Fault Responsive Protective Means,"
U.S. Patent No. 3,340,455

W. Kalbskoph, "Voltage-Compensating Transformer," U.S. Patent No. 2,173,905.

O. Kiltie, "Vibrator Current-Converting System" U.S. Patent No. 2,237,003.

O. Kiltie, "Phase Converter," U.S. Patent No. 2,359,768.

T.M. Corry, "Method of and Apparatus For Generating Three-Phase Sinusoidal Voltages,"
U.S. Patent No. 3,725,767.

T.M. Corry, "Electrical Inverter for Electric Vehicles," U.S. Patent No. 3,354,370.

T.M. Corry, "Thyristor Trigger Circuits," U.S. Patent No. 3,413,493.

T.M. Corry, "Electroluminescent Lamp Inverter Circuit," U.S. Patent No. 3,141,110.

T.M. Corry, "Electrical Power Supplies," U.S. Patent No. 2,937,298.

J. Roesel, T.M. Corry, "Solid State Fluorescent Lamp Power Supplies," U.S. Patent
No. 2,965,804.

T.M. Corry, "Rectifier-Inverter Motor Power Supply," U.S. Patent No. 3,430,123.

T.M. Corry, "Multiphase Electrical Generators," U.S. Patent No. 3,136,957.

T.M. Corry, "Pulse Shaping Circuit," U.S. Patent No. 3,517,299.

T.M. Corry, "Vehicle Electric Drive," U.S. Patent No. 3,551,685.

L.H. Walker, "Parallel Redundant Operation of Static Power Conditioners," IEEE
Conference Record of 1973 IAS.

T. Wolpert, "Uninterruptible Power Supply for Critical AC Loads - A New Approach,"
IEEE Conference Record of 1973 IAS.

S. Pro, "Power Conditioning for Satellite Systems," AD 660 532.

J.P. O'Conner, "Power Circuits for Optimum Stepped-Wave Output in Three-Phase Single-Way Static Inverters," AD 650 479.

W.M. Robinson, "E.I. A. Standards for Commutating Capacitors," IEEE International Semiconductor Power Converter Conference, May 1972.

A.J. Humphrey, B. Molsrytzki, "Inverter Paralleling Reactors," IEEE International Semiconductor Power Converter Conference, May 1972.

K. Thorborg, "A Three Phase Inverter with Reactive Power Control," IEEE International Semiconductor Power Converter Conference, May 1972.

T. Ikeda, "High Efficiency Synthetic Wave Inverter," U.S. Patent No. 3,391,323.

D.L. Bowles, M.A. Geyer, "The Central Inverter in a Spacecraft Power System" IEEE Transactions on Aerospace and Electronic Systems, Vol. AES-2, No. 4, July 1966.

E.J. Howard, "Variable Speed, Constant Frequency Electric Power Distribution Systems for Aircraft," IEEE Transactions on Aerospace and Electronic Systems, Vol. AES-2, No. 4, July 1966.

C.J. Amato, "Sub-Ripple Distortion Components in Practical Cycloconverters," IEEE Transactions on Aerospace, June 1965.

A.W. DiMaryio, "Graphical Solutions to Harmonic Analysis, IEEE Transactions on Aerospace and Electronic Systems, Vol. AES-4, No. 5, September 1968.

R.H. Murphy, K.P.P. Nambiar, "Silicon Controlled Rectifier Static Alternators," Proc. IEE, Vol. 110, No. 6, June 1963.

F.G. Turnbull, "Selected Harmonic Reduction in Static DC-AC Inverters," IEEE Summer General Meeting, July 1964.

J.J. Pierro, J.E. Phillips, "Investigation of High Frequency Power Conversion and Generator Techniques," IEEE Transactions on Aerospace, June 1965.

- S.Y. Merritt, "Interface Problems in the Use of Aerospace Static Power Conversion Equipment," IEEE Transactions on Aerospace, June 1965.
- H. Nyquist, "Apparatus and Method for Generating Pure Sine Waves of Electromotive Force," U.S. Patent No. 1,691,986.
- D.E. Ruch, "Circuit for Approximating a Desired Waveform Across a Load," U.S. Patent No. 3,310,730.
- P.R. Johannessen, "Pulse Width Modulated Amplifier and Method," U.S. Patent No. 2,990,516.
- B.F. McNamee, "Inverter Circuit," U.S. Patent No. 2,929,013.
- W.G. Hall, R.I. Van Nice, "Square Wave Phase Shifter," U.S. Patent No. 2,798,970.
- R.H. Lee, "Transistor Converters," U.S. Patent No. 3,089,075.
- B.M. Van Eniden, "Converter Circuit," U.S. Patent No. 3,010,062.
- D.J. Sikorra, "Saturable Reactor and Transistor Bridge Voltage Control Apparatus," U.S. Patent No. 3,233,161.
- A.P. Martin, "Power and Voltage Regulator Circuit," U.S. Patent No. 3,237,081.
- M.J. Geisler, "Inverter Network," U.S. Patent No. 3,246,226.
- A.M. Tailleir, "Regulated Power Supply," U.S. Patent No. 3,117,270.
- J.L. Jensen, "Semiconductor Apparatus," U.S. Patent No. 3,002,142.
- W.G. Evans, R.I. Van Nice, "Electrical Control Apparatus," U.S. Patent No. 2,740,086.
- R.H. Pintell, "Regulated Source of Alternating or Direct Current," U.S. Patent No. 2,968,738.
- J.W. Bates, "Voltage Phase Controller Employing Synchronized Square Wave Generators," U.S. Patent No. 3,205,424.
- R.E. Morgan, "Basic Magnetic Functions in Converters and Inverters Including New Soft Commutation," IEEE Conference Record of Industrial Static Power Conversion Conference, November 1965.

Schaeffer, Rectifier Circuits: Theory and Design, Wiley and Sons, 1965.

M. Alsamatsu, M. Kumaro, S. Yaro, "High Performance Thyristor Commutation Method and Its Applications," USASTCFEO Report No. 2, 253 0385 73.

J. Reeve, T. Rao, "Dynamic Analysis of Harmonic Interaction Between AC and DC Power Systems," IEEE Transactions on Power Apparatus and Systems, March 1974, Vol. PAS-93, No. 2.

H. Sasaki, T. Machida, "Transient Analysis of Harmonic Current Elimination Method by Magnetic Flux Compensation," IEEE Transactions on Power Apparatus and Systems, March 1974, Vol. PAS-93, No. 2.

K. Kishi, K. Takigami, M. Morohoshi, A. Takenaka, "Ultra High-Speed Solid-State Circuit Breakers for AC and DC Power Lines," IEEE Power Electronics Specialists Conference, June 1974.

B.R. Lelly, Thyristor Phase-Controlled Converters and Cycloconverters, Wiley-Interscience, 1971.

T. Hasumi, H. Kasahara, T. Tanaka, "Design of a Thyristor Frequency Converter Aided by Computer Simulation," PESC 74 Record.

S.B. Dewan, G. Havas, "A Solid State Supply for Induction Heating and Melting," IEEE Transactions, IGA Vol. IGA-5, No. 6, Nov/Dec, 1969.

K.C. Elliott, W. Elliott, "Open-Wye-Type Phase Conversion Systems," IEEE Transactions IGA, Vol. IGA-6, No. 2, March/April 1970.

S.B. Dewan, P.B. Biringer, "Harmonic Analysis of AC-to-AC Frequency Converter," IEEE Transactions, IGA Vol. IGA-5, No. 1, Jan/Feb, 1969.

W. McMurray, "The Thyristor Electronic Transformer: A Power Converter Using a High-Frequency Link," IEEE Transactions, IGA, Vol. IGA-7, No. 4, July/August, 1971.

E. Schnonholzer, "Fuse Protection for Power Thyristors," IEEE Transactions on Industry Applications, Vol. IA-8, No. 3, May/June 1972.

W. McMurray, "Optimum Snubbers for Power Semiconductors," IEEE Transactions on Industry Applications, Vol. IA-8, No. 5, Sept/Oct, 1972.

S. Jackson, "Multiple Pulse Modulation in Static Inverters Reduces Selected Output Harmonics and Provides Smooth Adjustment of Fundamentals," IEEE Transactions IGA, Vol. IGA-6, No. 4, July/Aug, 1970.

Z.H. Meiksin, "Comparison of Orthogonal and Parallel-Flux Variable Inductors," IEEE Transactions on Industry Applications, Vol. 1A-10, No. 3, May/June, 1974.

Z.H. Meiksin, "Orthogonal-Flux Parametric Voltage Regulator," IEEE Transactions on Industry Applications, Vol. 1A-10, No. 3, May/June, 1974.

Z.H. Meiksin, "Parallel-Flux Parametric Voltage Regulator and Comparison with Orthogonal-Flux Parametric Voltage Regulator," IEEE Transactions in Industry Applications, Vol. 1A-10, No. 3, May/June, 1974.

H.J. Ruhl, Jr., P.O. Shafer, "Recent Developments in the Measurement of Thyristor Turn-Off Time," IEEE 1974 IAS Transactions.

S.B. Dewan, Ken Gallant, "Analysis of a Single Phase Current Source Inverter," IEEE 1974 IAS Transactions.

C.J. Nordby, "Characteristics of a Highly Efficient Auto-Commutated Power Circuit," IEEE 1974 IAS Transactions.

D.W. Borst, G. Dydek, G. Geissinger, "To Fuse or Not to Fuse Power Thyristors," IEEE 1974 IAS Transactions.

T. Yatsuo, T. Kamei, Y. Terasawa, T. Ogawa, "High Voltage, High Speed Reverse Conducting Thyristors," IEEE 1974 IAS Transactions.

L. Hire, "Thermal Considerations of A/C Resonating Capacitors in Ferroresonant Applications," IEEE 1974 IAS Transactions.

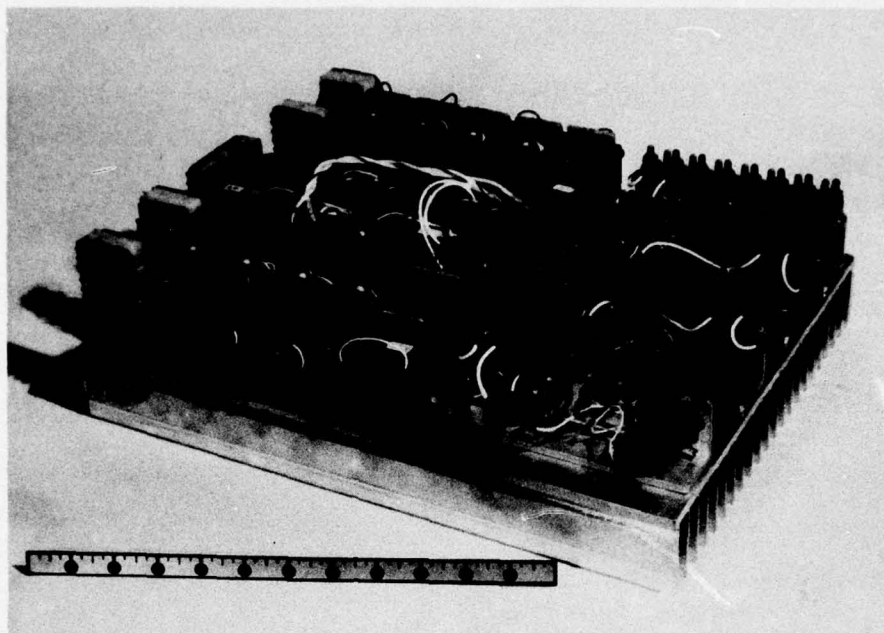


Figure 1. Item 0001 Inverter Power Switch Assembly

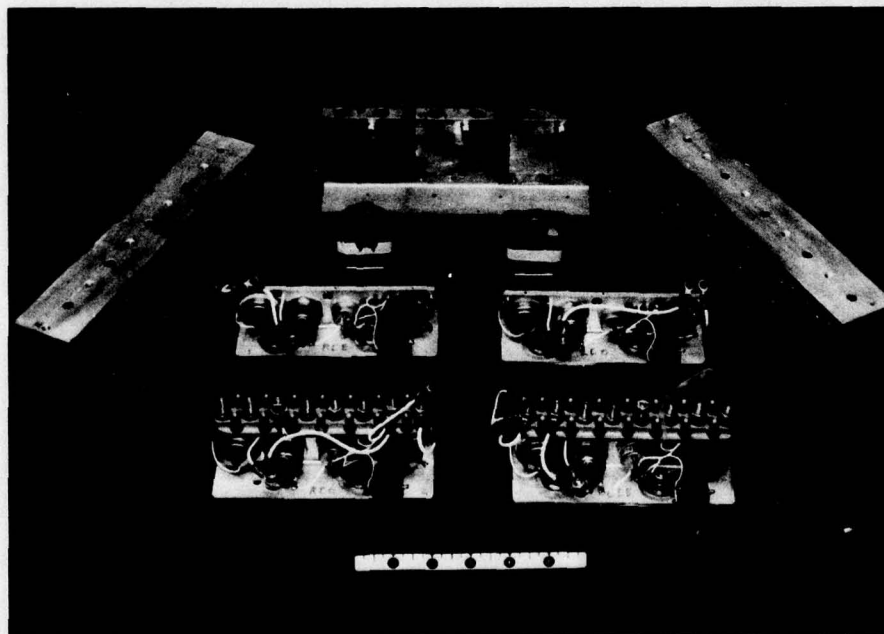


Figure 2. Transistor Step Commutation Circuit Components Removed from Item 0001 Inverter

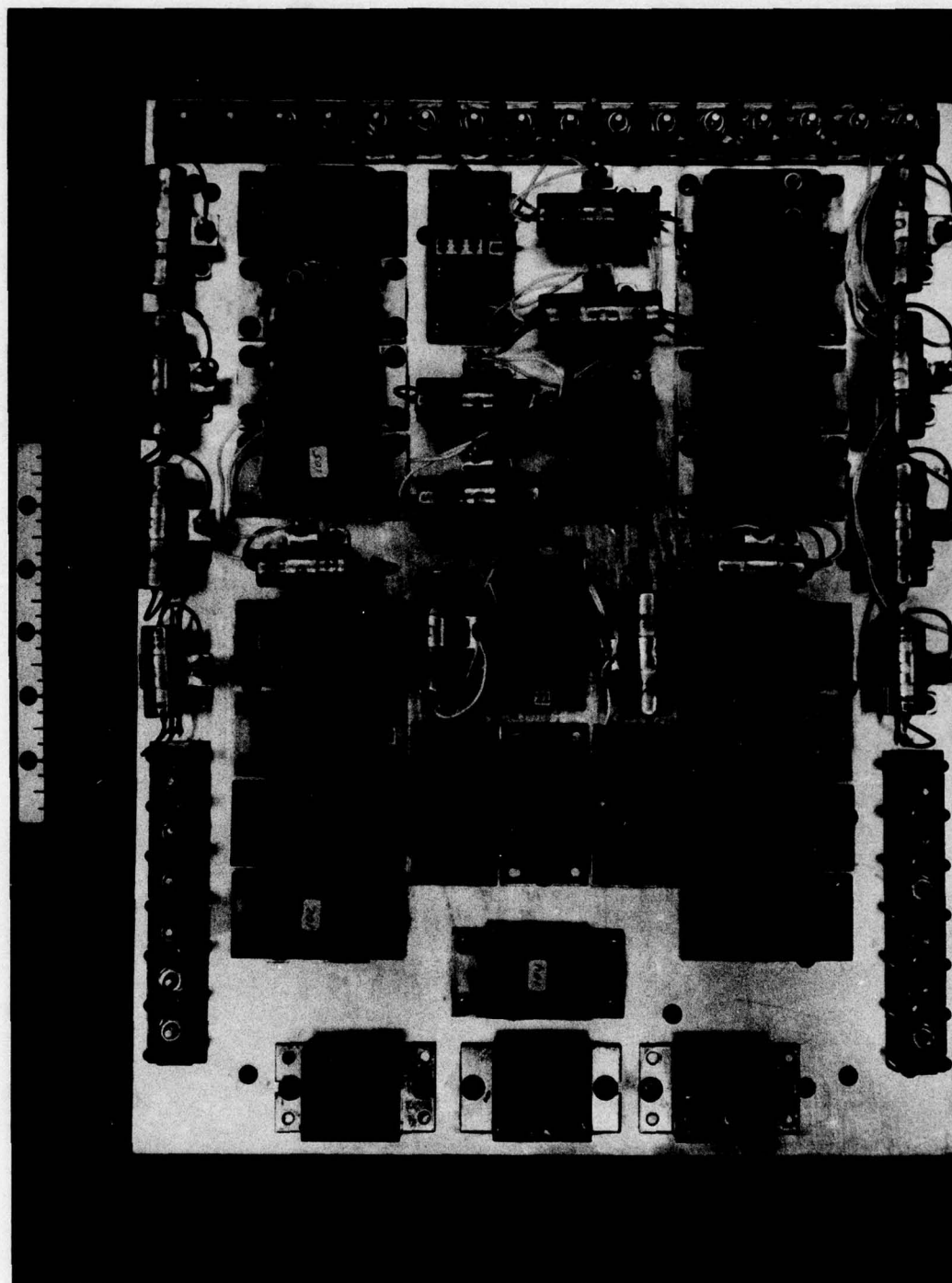


Figure 3. Item 0006 Inverter with Thyristor Step Commutation. Weight 23 lb



Figure 4. Threequarter View of Item 0006 Inverter Power Switch Assembly

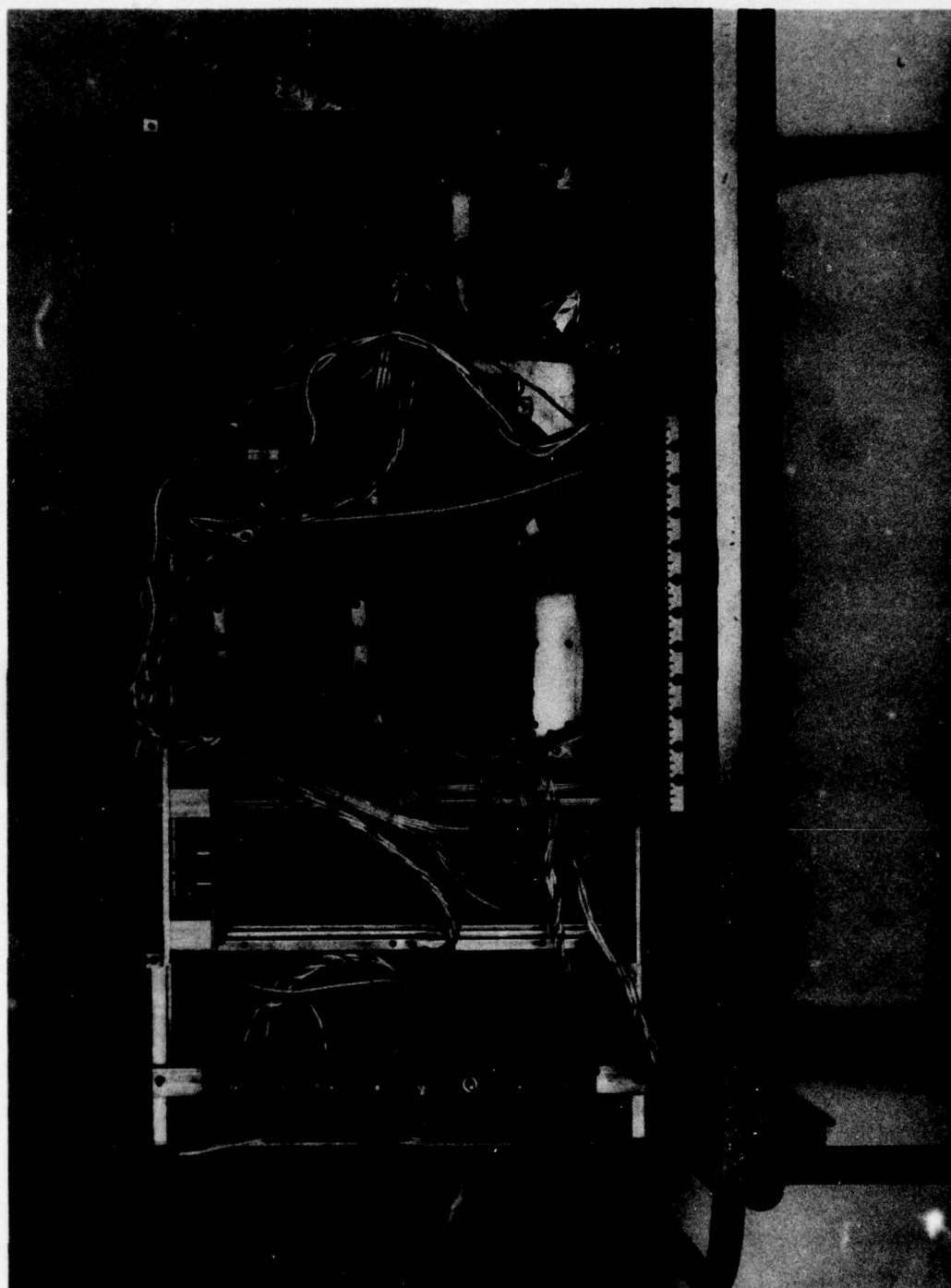


Figure 6. Item 0006 Inverter - Bottom View

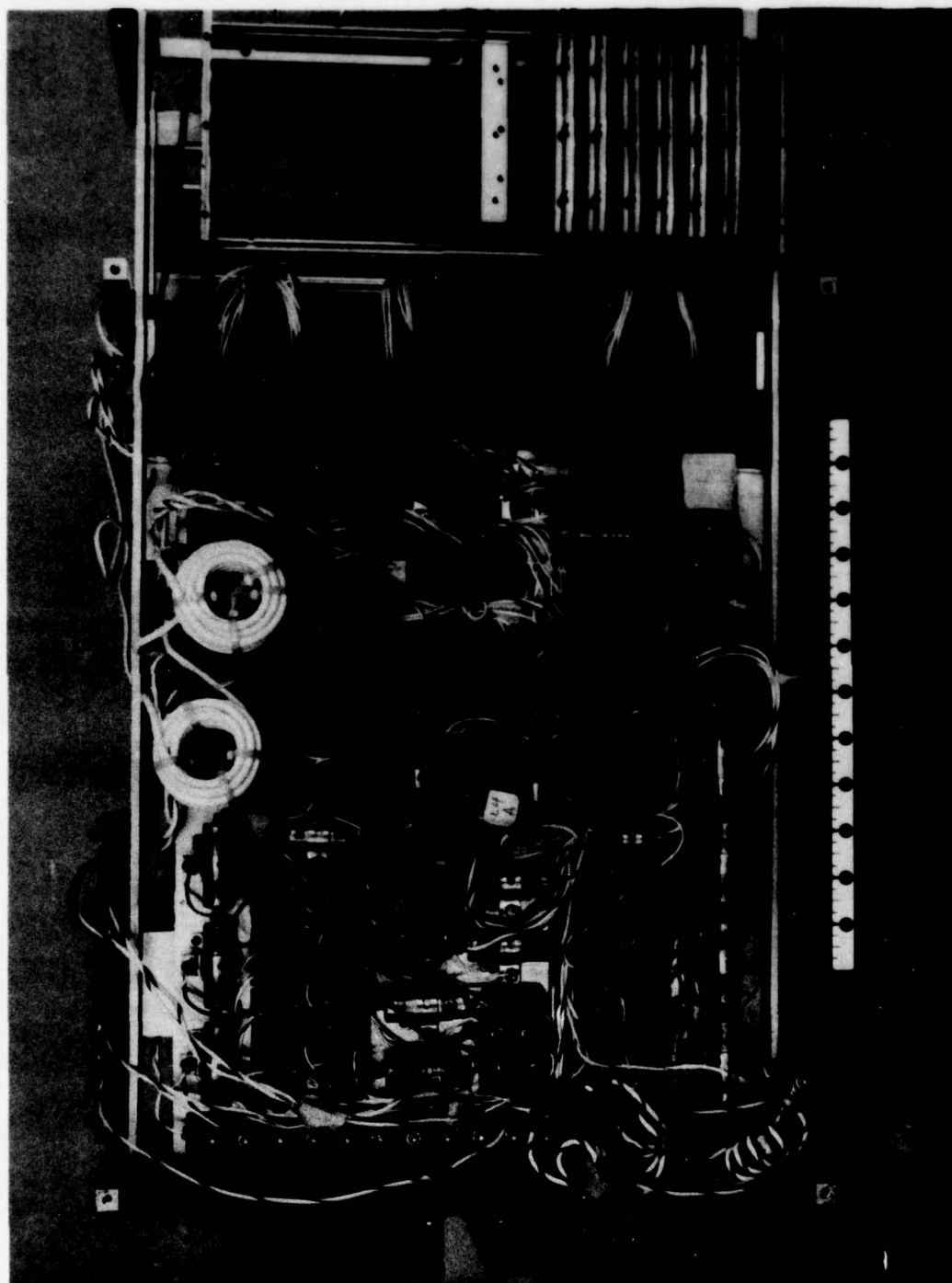


Figure 7. Item 0006 Inverter - Top View

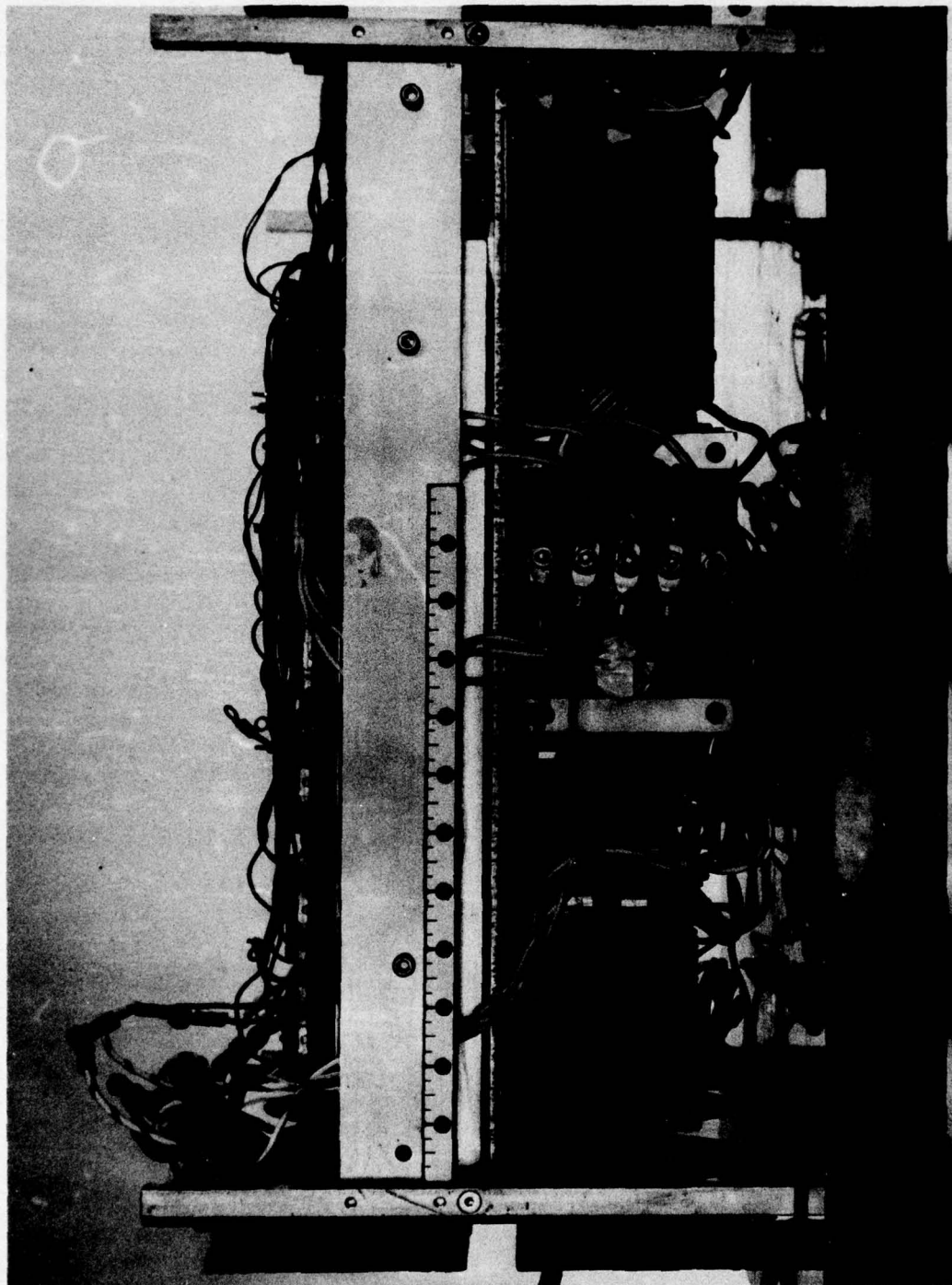


Figure 8. Item 0006 Inverter - Side View

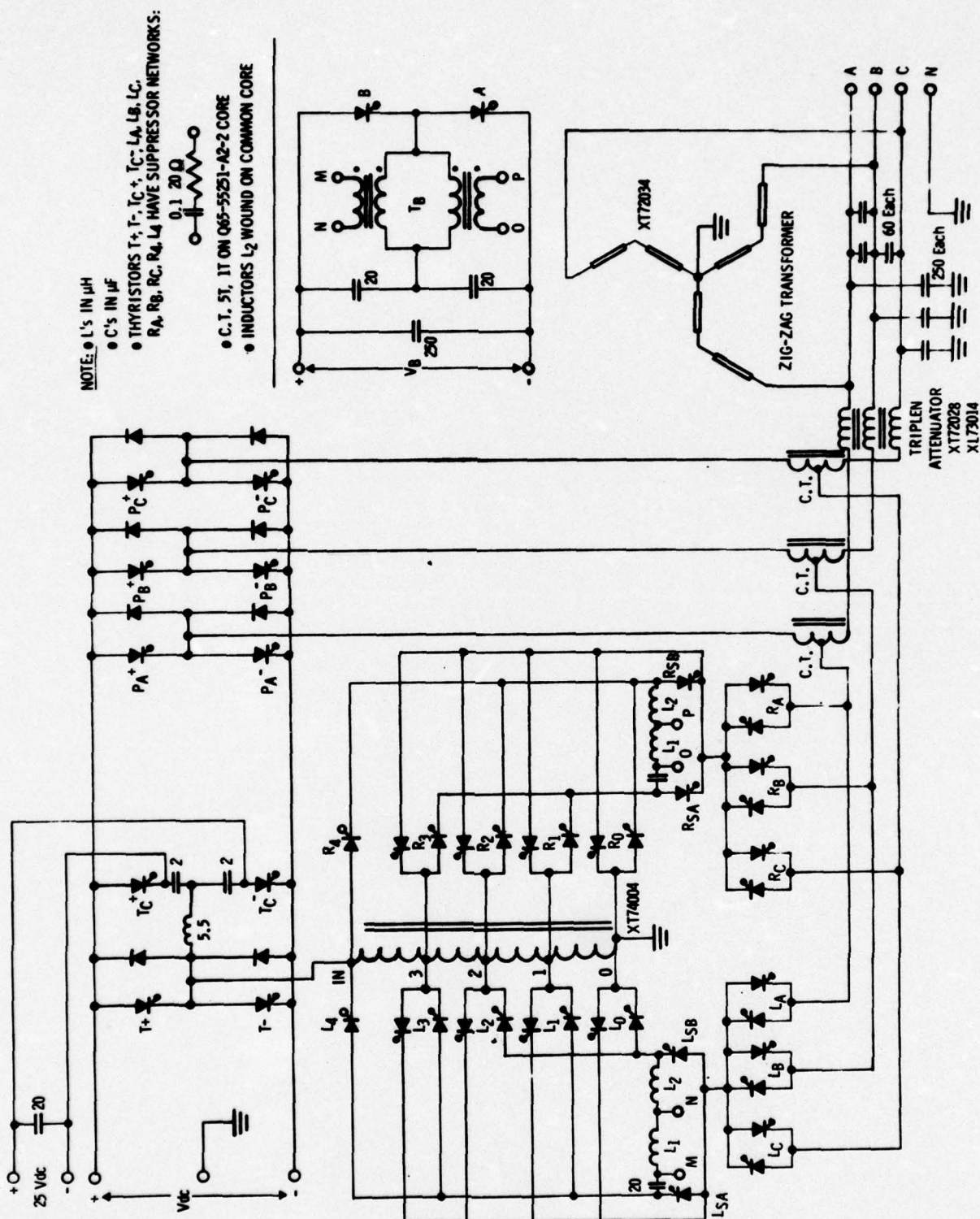


Figure 9. 60 Hz Inverter Circuit

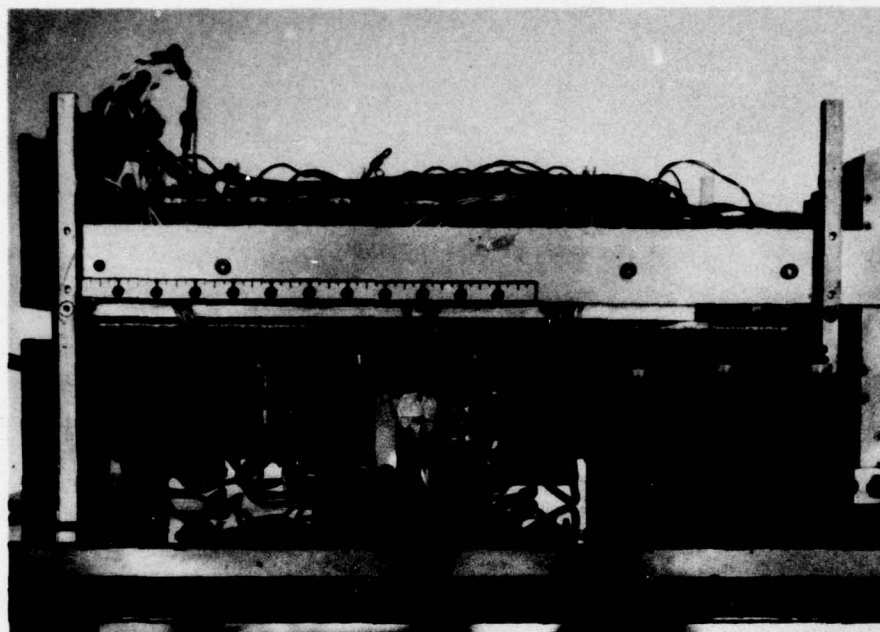


Figure 10. Item 0006 Inverter Showing Addition of 60 Hz Output Filter Capacitors

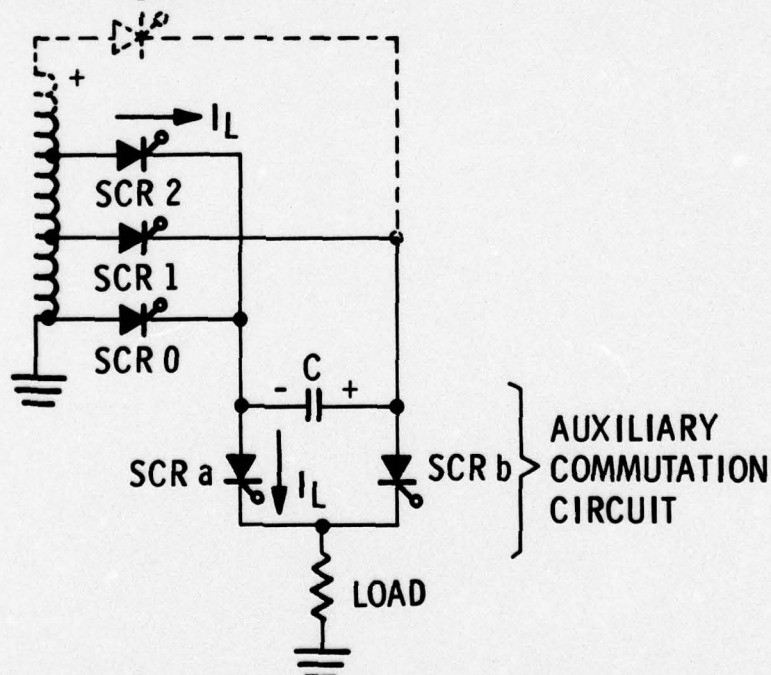


Figure 11. Double Bus Step Changing Circuit

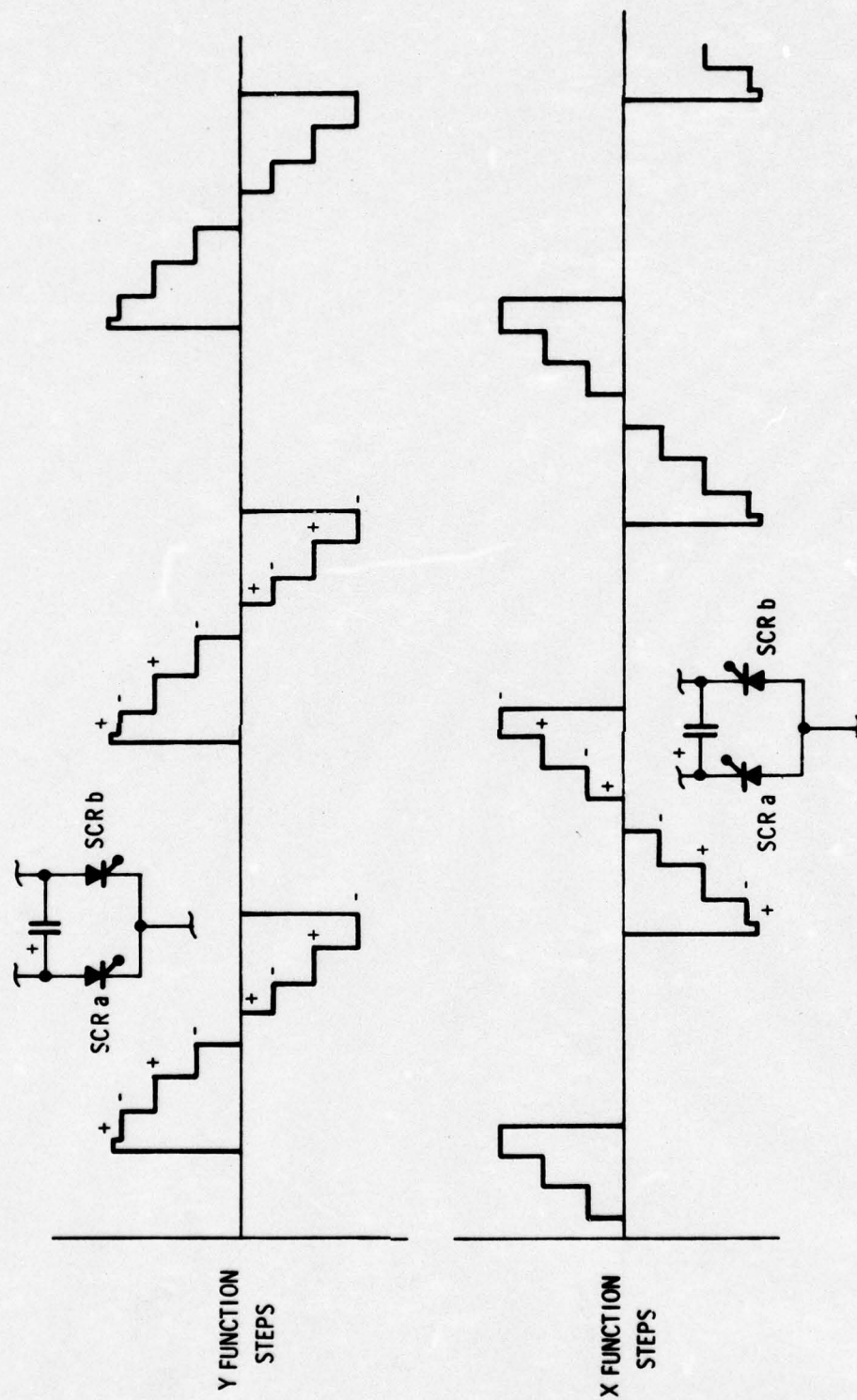


Figure 12. Diagram Showing the Capacitor Voltage Polarities Required to Commutate Each Step for the Y and X Functions

Y FUNCTION CIRCUIT

X FUNCTION CIRCUIT

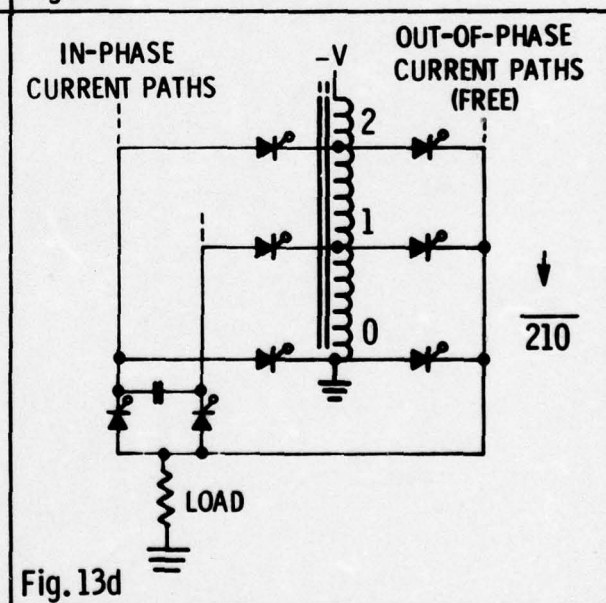
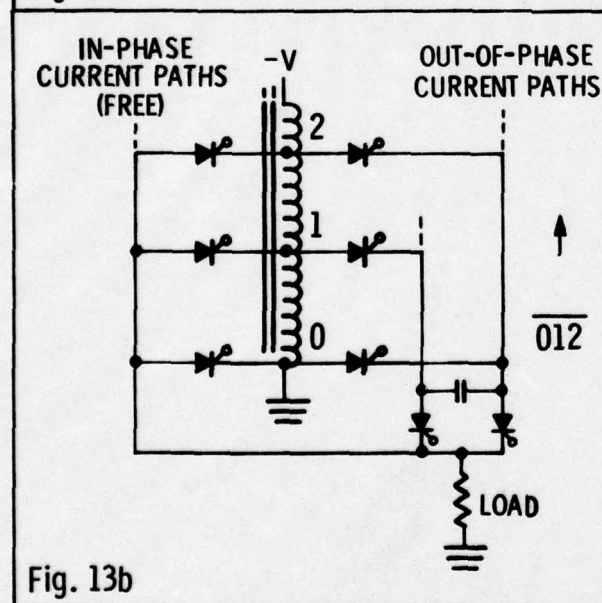
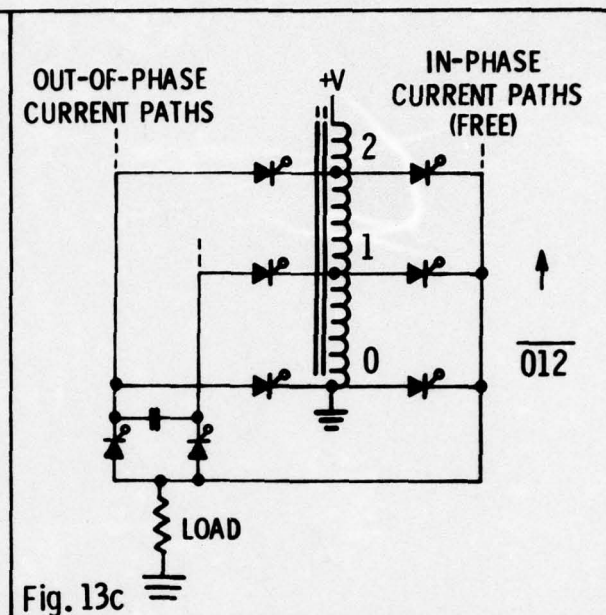
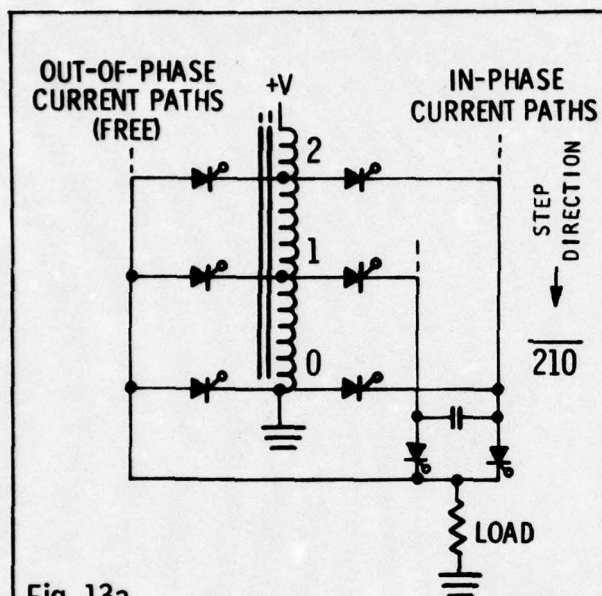


Figure 13. Y and X Step Function Circuits

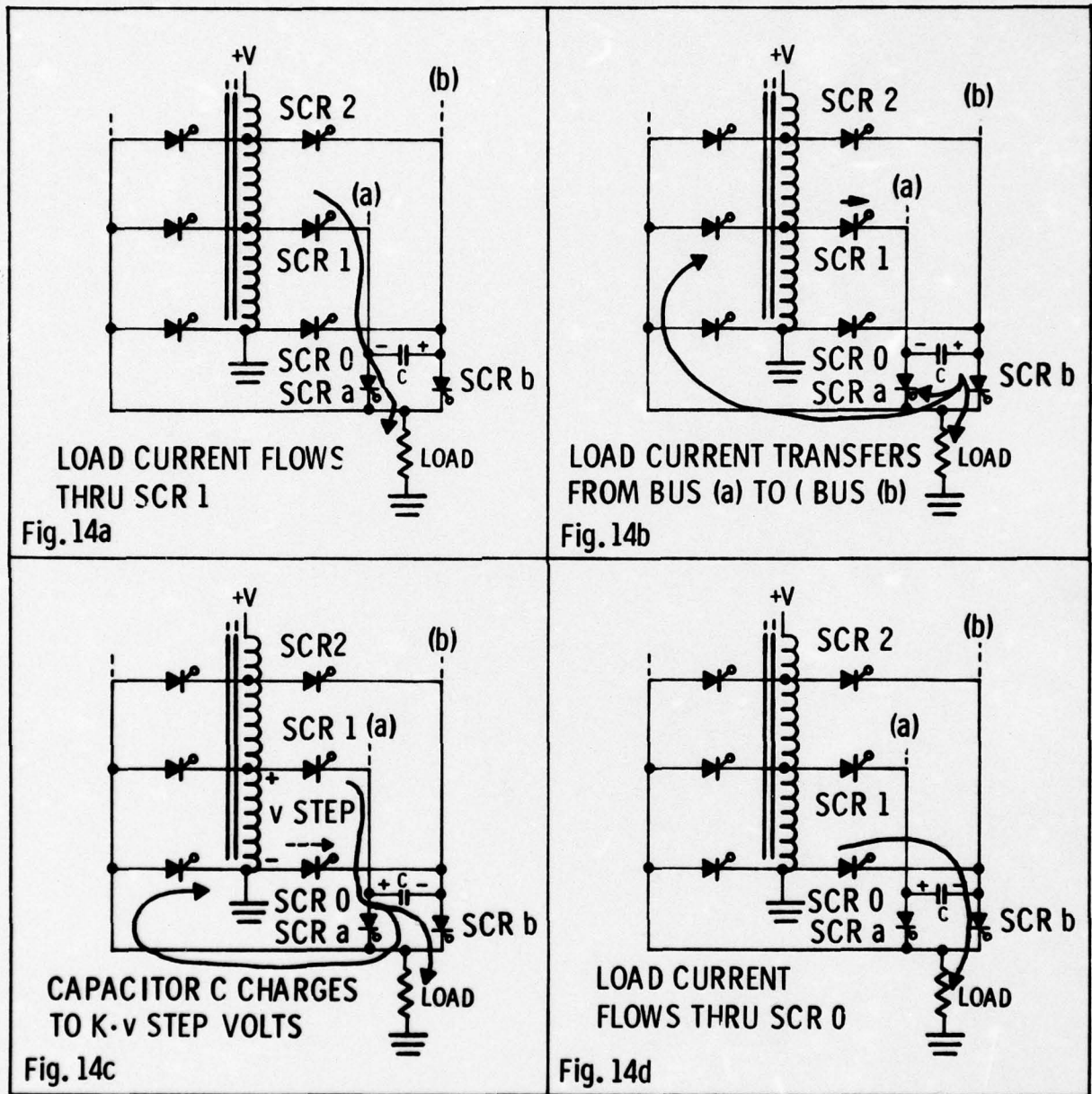


Figure 14. Y Function. Transferring Current from SCR1 to SCR0.
Load Voltage and Current Flow Positive

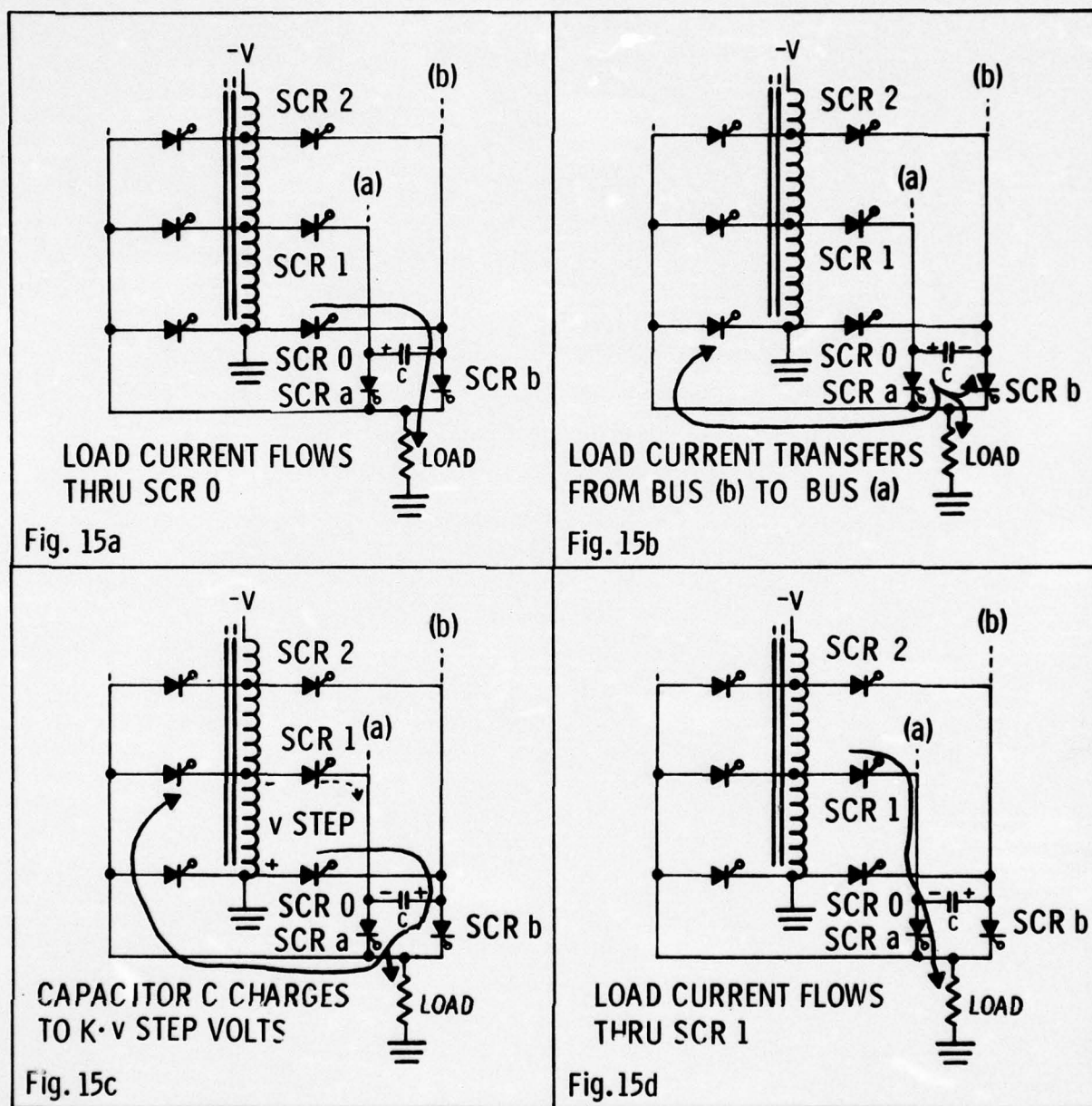


Figure 15. Y Function. Transferring Current from SCR0 to SRC1. Load Voltage Negative; Current Flow Positive

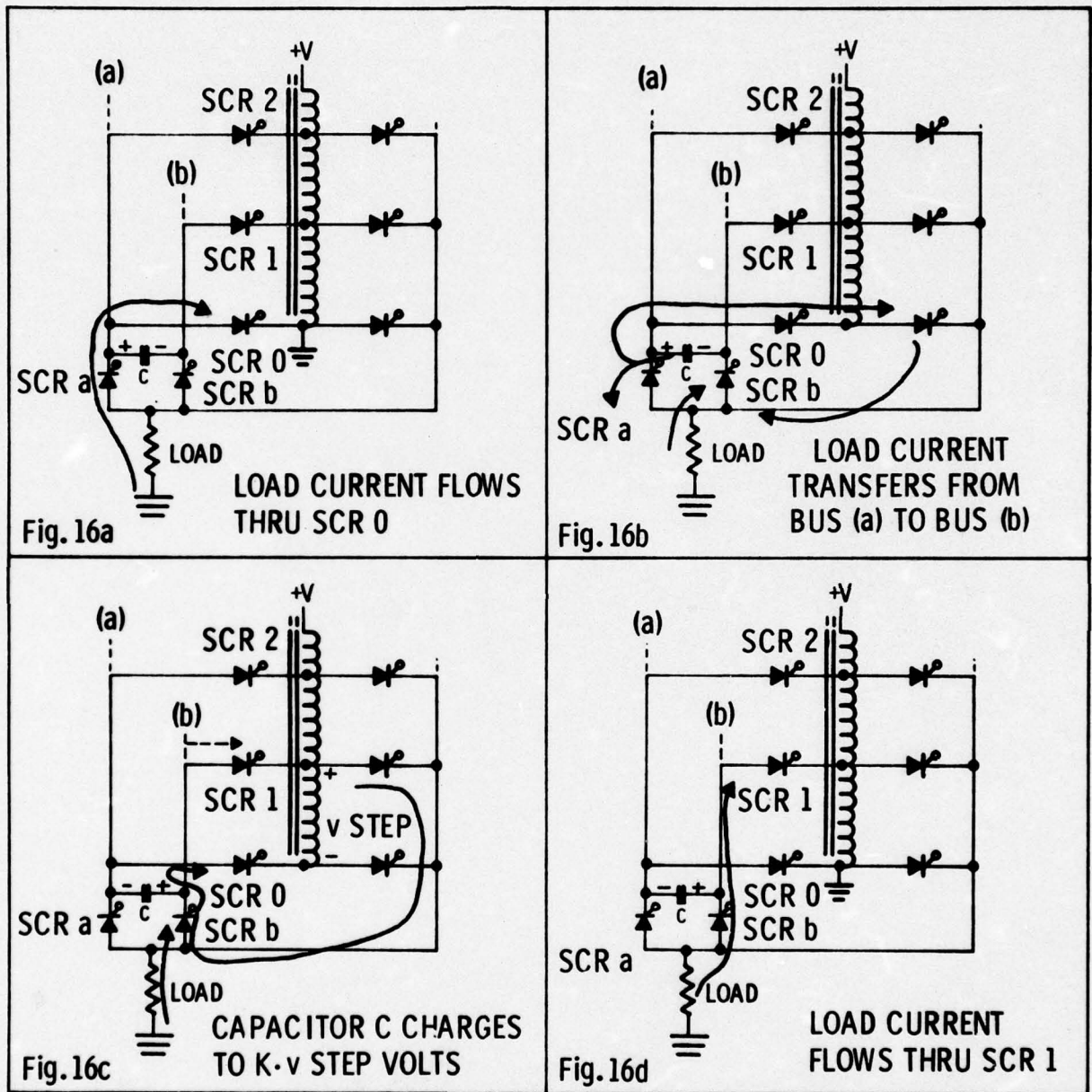


Figure 16. X Function. Transferring Current from SCR0 to SCR1. Load Voltage Positive; Current Flow Negative

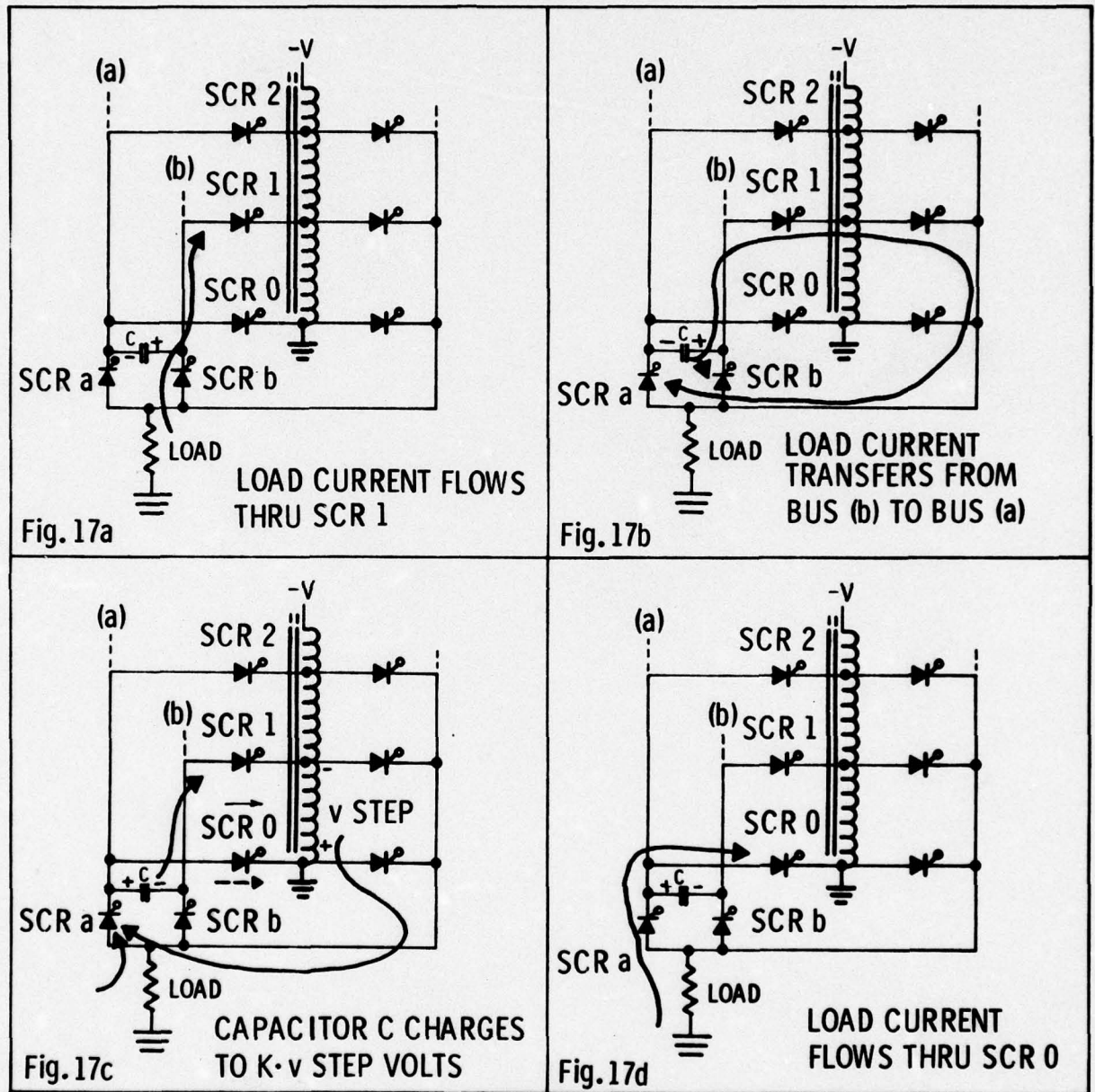


Figure 17. X Function. Transferring Current from SCR1 to SCR0. Load Voltage and Current Flow Negative

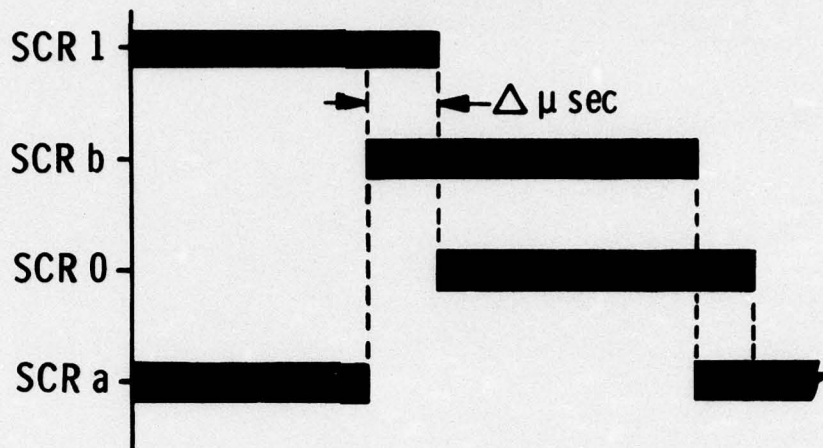


Figure 18a. SCR Trigger Timing Sequence for Figures 14a to 14d

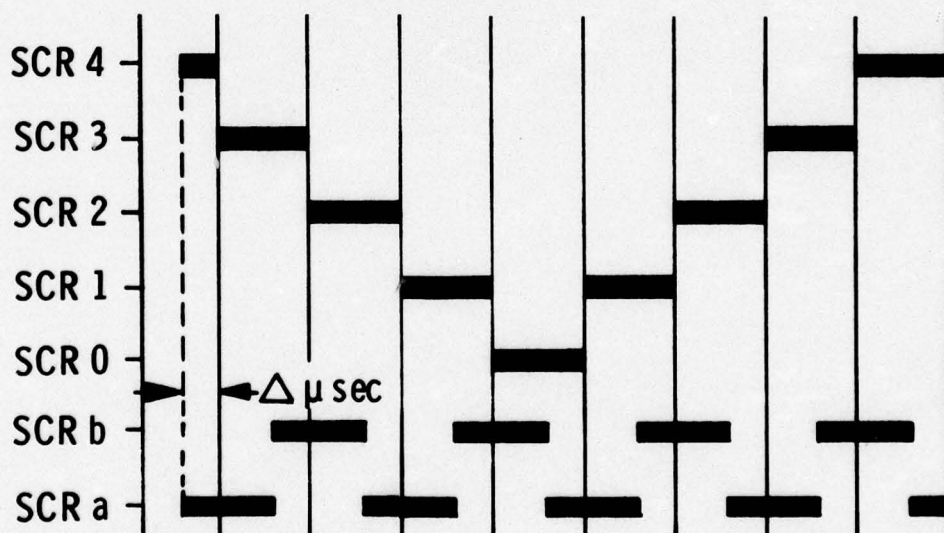


Figure 18b. Y Function Step Timing Diagram

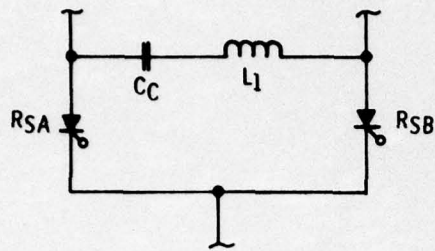


Figure 19a. Basic Step Voltage Commutation Circuit

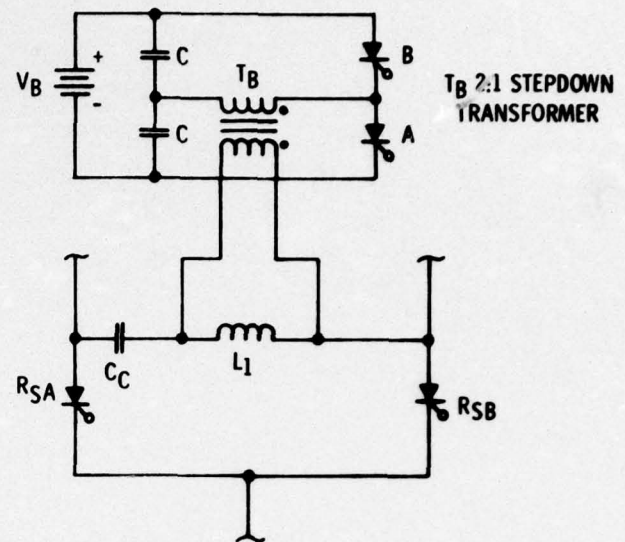


Figure 19b. Method of Obtaining Boost Voltage for Step Commutation

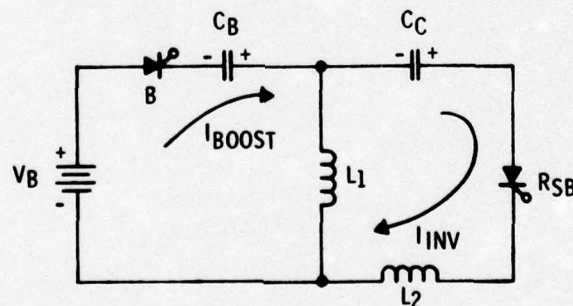
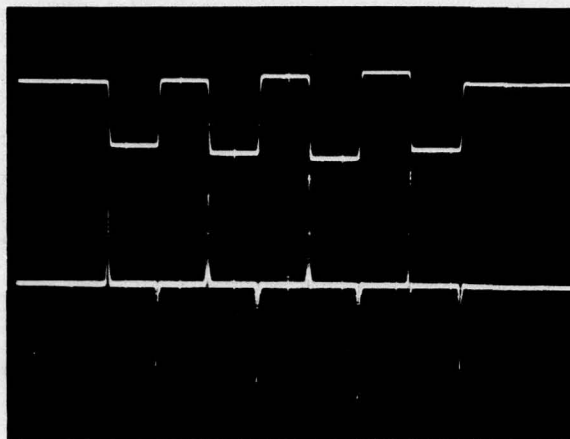


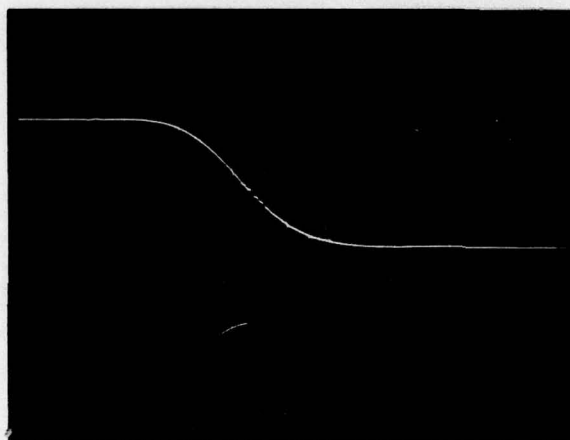
Figure 20. Twin Resonant Circuit with Common Inductor for Energy Transfer Between Circuits. Thyristors R_{SB} and B Turn-on Simultaneously



COMMUTATION CAPACITOR C_C
VOLTAGE 200 V/DIV.

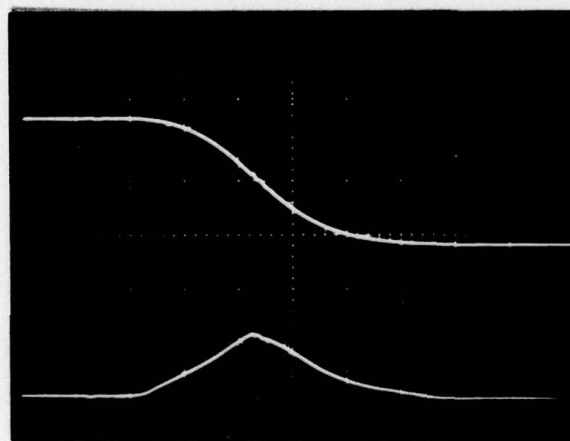
(a) COMMUTATION CAPACITOR C_C
CURRENT 100 A/DIV.

500 μ SEC/DIV.; $V_B = 66$ VDC; $I_B = 9$ AMPS
0 INPUT VOLTAGE TO 1 INVERTER



COMMUTATION CAPACITOR C_C
VOLTAGE AT POWER CENTER
COMMUTATION TIME, P_C 100 V/DIV.

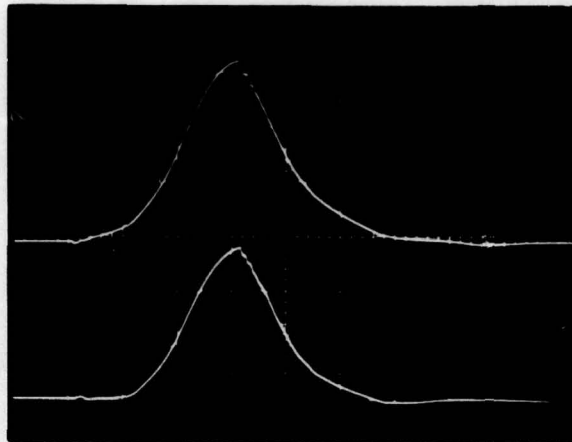
(b) COMMUTATION CAPACITOR C_C
CURRENT 200 A/DIV.
10 μ SEC/DIV.
0 INPUT VOLTAGE TO INVERTER



COMMUTATION CAPACITOR C_C
VOLTAGE 100 V/DIV.

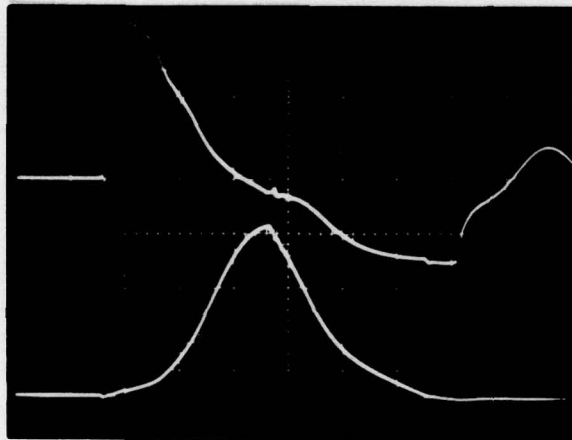
(c) COMMUTATION CAPACITOR C_C
CURRENT 200 A/DIV.
10 μ SEC/DIV.
11 kW, PF = 0.8 LOAD

Figure 21. Voltage and Current Waveforms for the Commutation Boost Circuit
(Sheet 1 of 6)



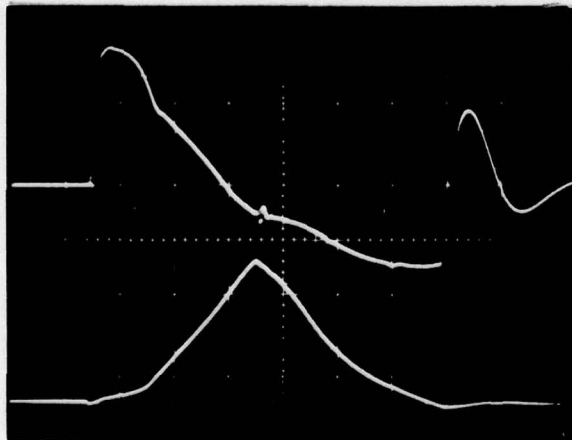
INDUCTOR L_1 CURRENT
100 A/DIV.

(d) COMMUTATION CAPACITOR C_C
CURRENT 100 A/DIV.
10 μ SEC/DIV.



INDUCTOR L_1 VOLTAGE
20 V/DIV.

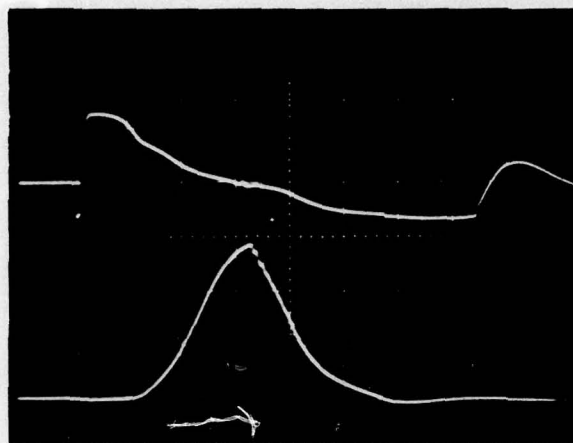
(e) INDUCTOR L_1 CURRENT
100 A/DIV.
10 μ SEC/DIV.
0 INPUT VOLTAGE TO INVERTER



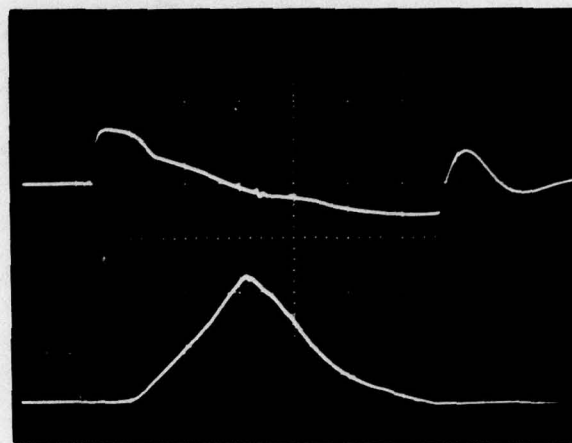
INDUCTOR L_1 VOLTAGE
20 V/DIV.

(f) INDUCTOR L_1 CURRENT
100 A/DIV.
10 μ SEC/DIV.
11 kW, PF = 0.8 LOAD

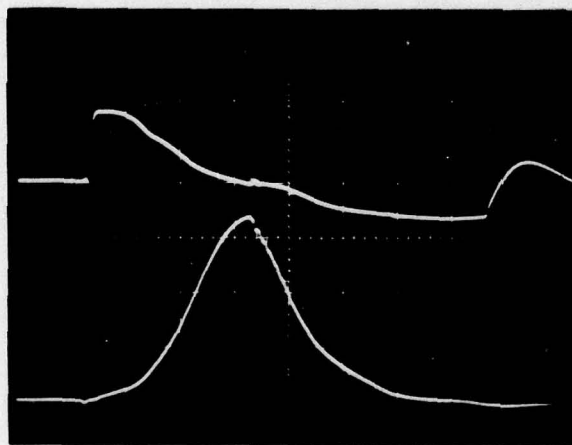
Figure 21. Voltage and Current Waveforms for the Commutation Boost Circuit
(Sheet 2 of 6)



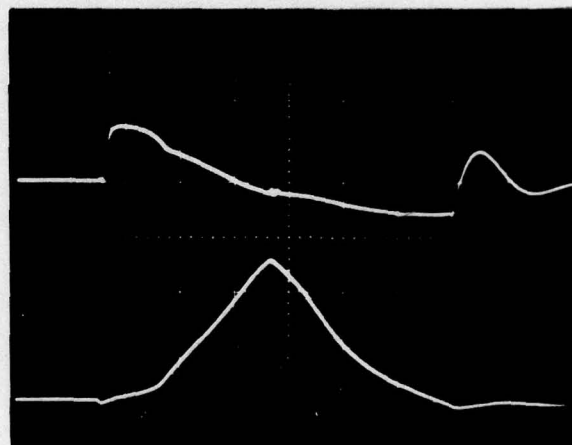
(g) UPPER TRACE INDUCTOR L_1 VOLTAGE 50 V/DIV.
LOWER TRACE COMMUTATION CAPACITOR C_C CURRENT 100 A/DIV.
10 μ SEC/DIV.
0 INPUT VOLTAGE TO INVERTER



(h) UPPER TRACE INDUCTOR L_1 VOLTAGE 50 V/DIV.
LOWER TRACE COMMUTATION CAPACITOR C_C CURRENT 100 A/DIV.
10 μ SEC/DIV.
11 kW PF = 0.8 LOAD

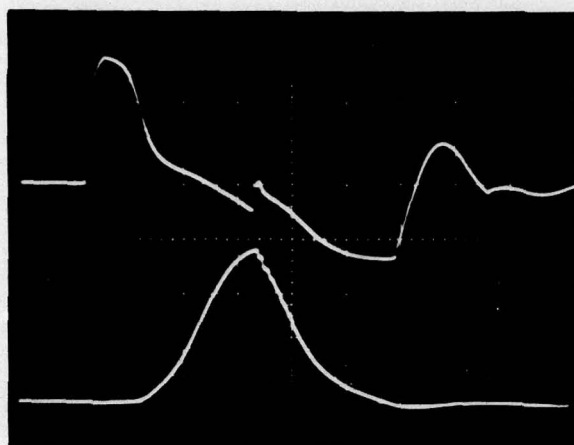


(i) UPPER TRACE TRANSFORMER T_8 SECONDARY VOLTAGE 50 V/DIV.
LOWER TRACE TRANSFORMER T_8 SECONDARY CURRENT 100 A/DIV.
10 μ SEC/DIV.
0 INPUT VOLTAGE TO INVERTER

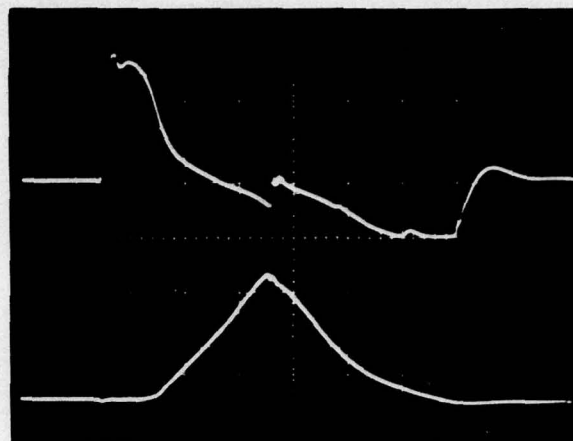


(j) UPPER TRACE TRANSFORMER T_8 SECONDARY VOLTAGE 50 V/DIV.
LOWER TRACE TRANSFORMER T_8 SECONDARY CURRENT 100 A/DIV.
10 μ SEC/DIV.
11 kW, PF = 0.8 LOAD

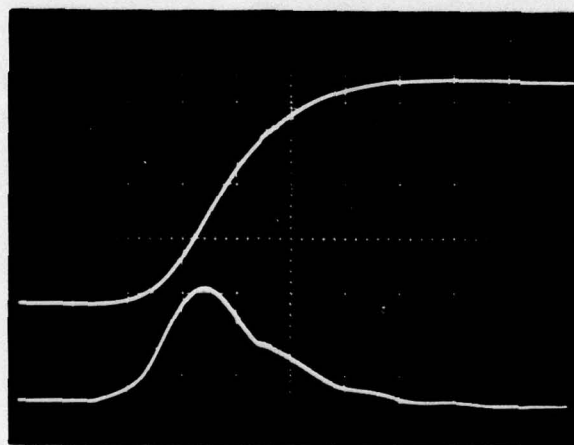
Figure 21. Voltage and Current Waveforms for the Commutation Boost Circuit
(Sheet 3 of 6)



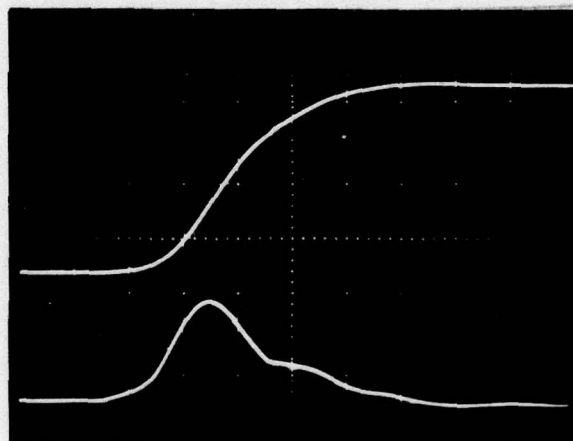
UPPER TRACE INDUCTOR L_2 VOLTAGE
100 V/DIV.
(k) LOWER TRACE COMMUTATION CAPACITOR
CURRENT 100 A/DIV.
10 μ SEC/DIV.
0 INPUT VOLTAGE TO INVERTER



UPPER TRACE INDUCTOR L_2 VOLTAGE
100 V/DIV.
(l) LOWER TRACE COMMUTATION CAPACITOR
CURRENT 100 A/DIV.
10 μ SEC/DIV.
11 kW, PF = 0.8 LOAD

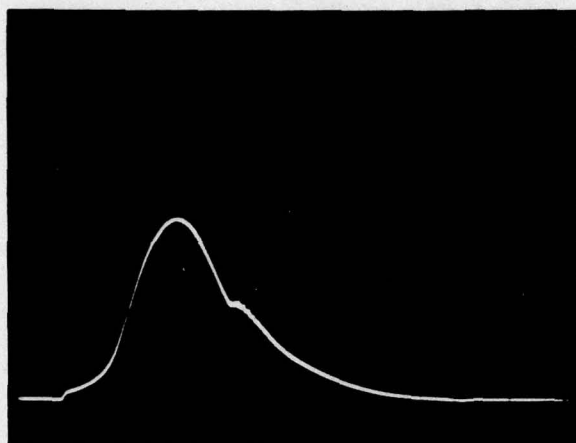


UPPER TRACE BOOST SUPPLY CAPACITOR C
VOLTAGE 50 V/DIV.
(m) LOWER TRACE BOOST SUPPLY CAPACITOR C
CURRENT 100 A/DIV.
10 μ SEC/DIV.
0 INPUT VOLTAGE TO INVERTER



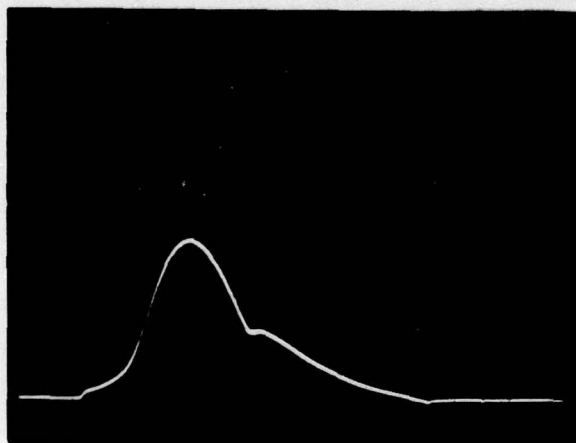
UPPER TRACE BOOST SUPPLY CAPACITOR C
VOLTAGE 50 V/DIV.
(n) LOWER TRACE BOOST SUPPLY CAPACITOR C
CURRENT 100 A/DIV.
10 μ SEC/DIV.
11 kW, PF = 0.8 LOAD

Figure 21. Voltage and Current Waveforms for the Commutation Boost Circuit
(Sheet 4 of 6)



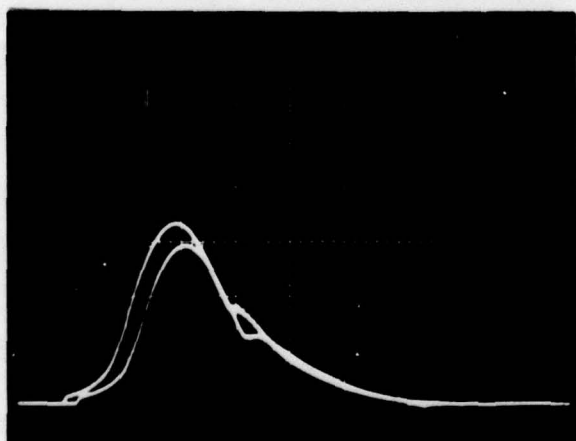
(o) BOOST SUPPLY CURRENT I_B
100 A/DIV.
10 μ SEC/DIV.

0 INPUT VOLTAGE TO
INVERTER



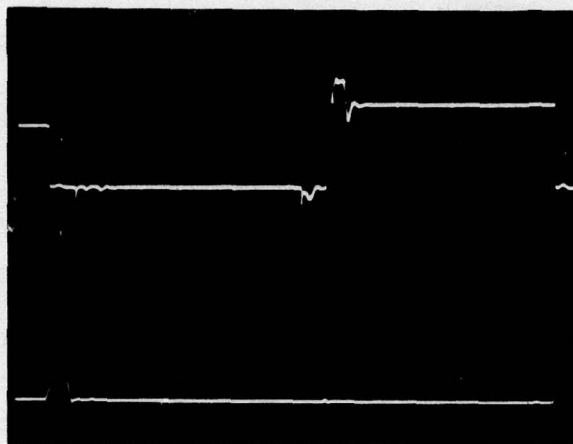
(p) BOOST SUPPLY CURRENT I_B
100 A/DIV.
10 μ SEC/DIV.
11 kW, PF = 0.8 LOAD

(AVG INPUT CURRENT DROPS
FROM 9 AMPS AT NO LOAD TO
8 AMPS AT 11 kW, 0.8 PF LOAD)

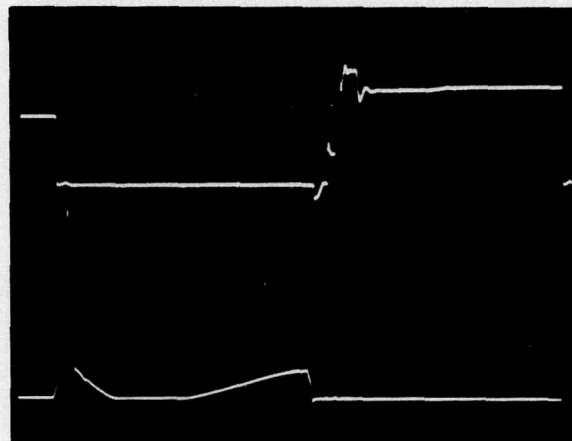


(q) DOUBLE EXPOSURE FOR
PICTURES O AND P

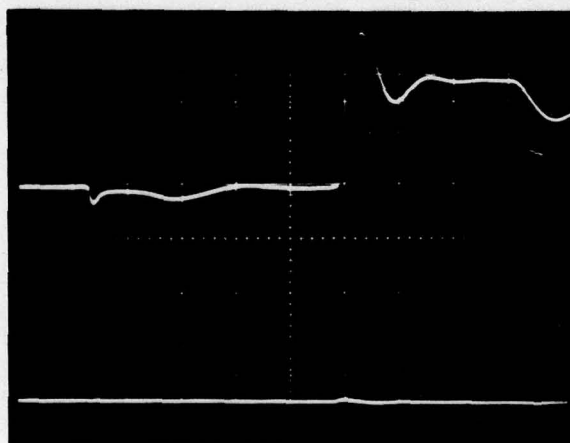
Figure 21. Voltage and Current Waveforms for the Commutation Boost Circuit
(Sheet 5 of 6)



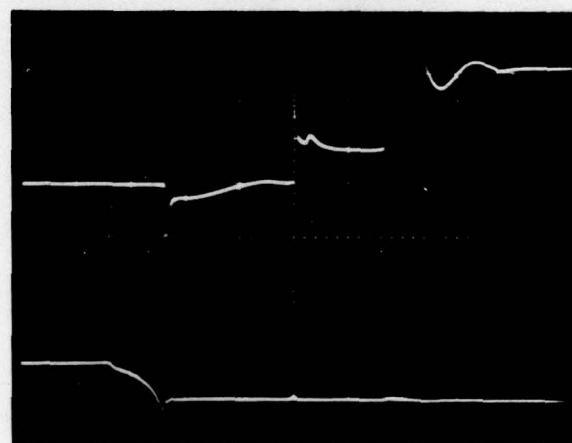
(r) UPPER TRACE VOLTAGE ACROSS THYRISTOR
TRACE R_{SA} FOR THIRD STEP LEVEL
100 V/DIV.
LOWER TRACE R_{SA} CURRENT
100 A/DIV.
100 μ SEC/DIV. NO LOAD



(s) UPPER TRACE VOLTAGE ACROSS THYRISTOR
TRACE R_{SA} FOR THIRD STEP LEVEL
100 V/DIV.
LOWER TRACE R_{SA} CURRENT
100 A/DIV.
100 μ SEC/DIV.
11 kW, PF = 0.8 LOAD



(t) SAME AS (r) BUT TIME = 10 μ SEC/DIV.



(u) SAME AS (s) BUT TIME = 10 μ SEC/DIV.

Figure 21. Voltage and Current Waveforms for the Commutation Boost Circuit
(Sheet 6 of 6)

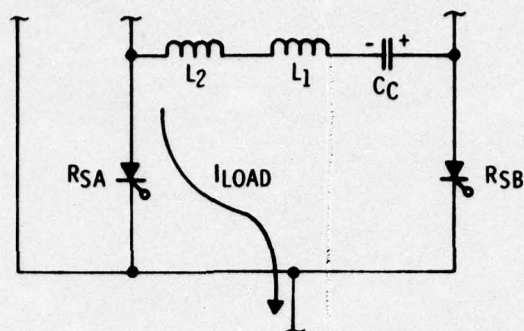


Figure 22a. Equivalent Commutation Circuit When Current Flows through R_{SA}

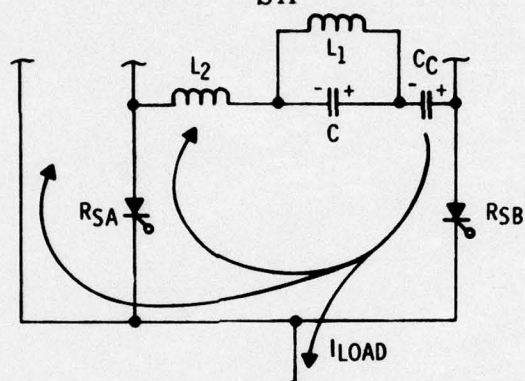


Figure 22b. Equivalent Commutation Circuit When R_{SB} Turns on to Commutate R_{SA} and Transfer Load Current to Another Step Voltage level

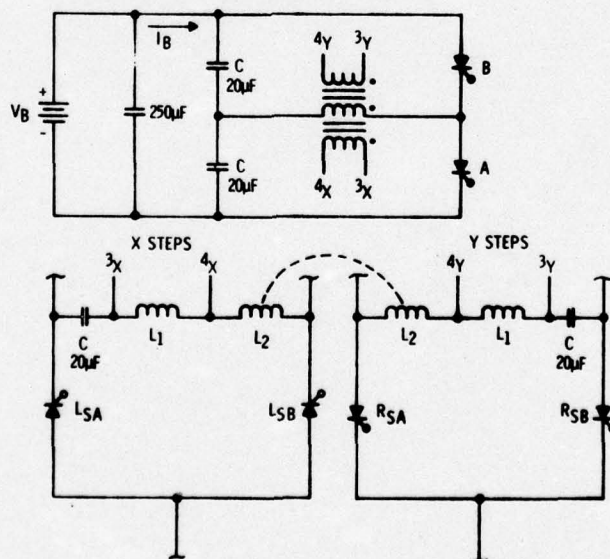
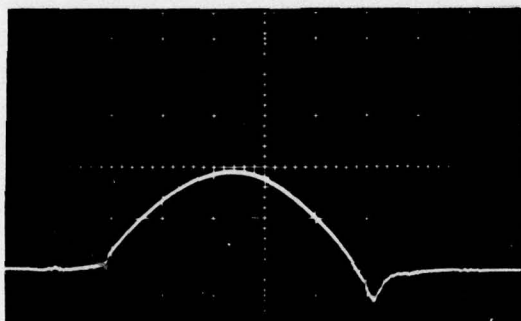
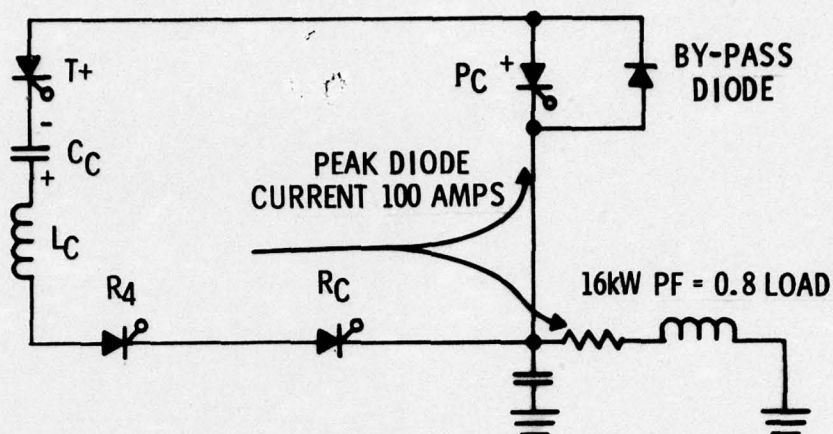
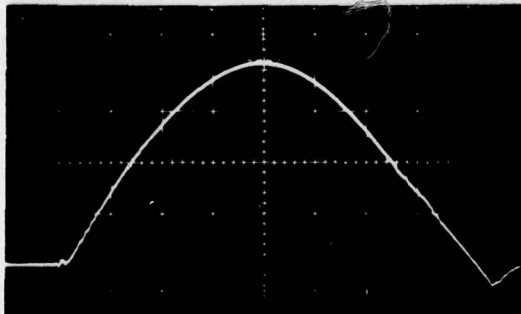


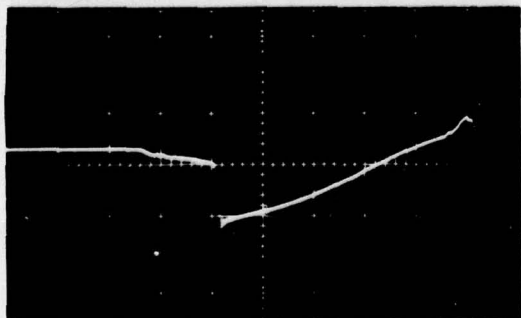
Figure 23. Complete Step Voltage Commutation Circuit



BY-PASS DIODE CURRENT
50A/div
5μsec/div

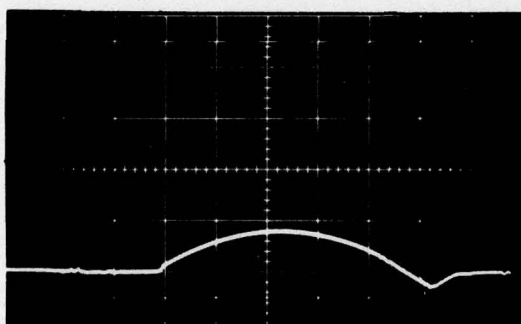
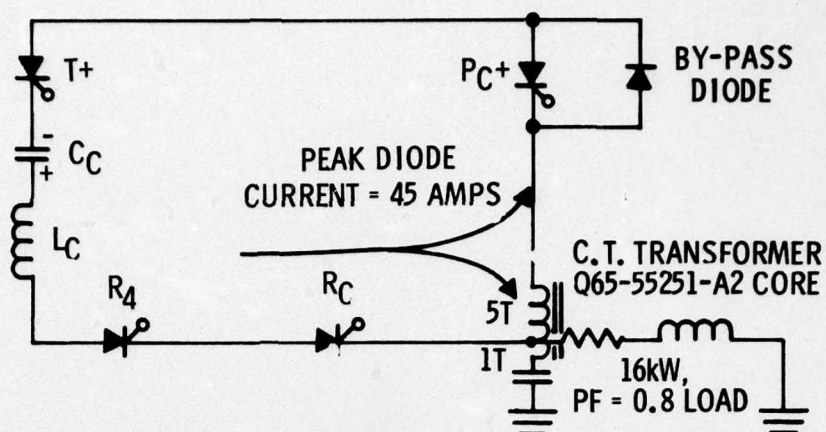


COMMUTATION CAPACITOR (C_C)
CURRENT
50A/div
5μsec/div



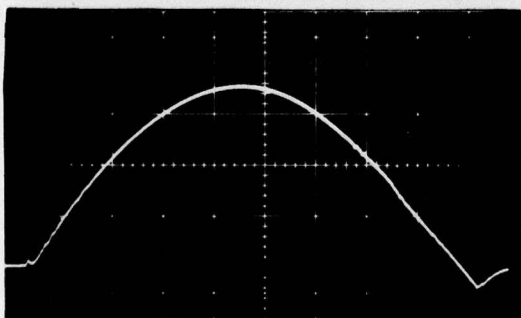
REVERSE TURN-OFF VOLTAGE
ACROSS THYRISTOR P_C+
5V/div
5μsec/div

Figure 24. Original Power Center Thyristor Turn-Off Circuit



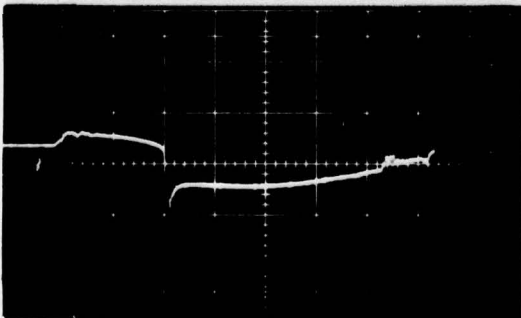
BY-PASS DIODE CURRENT

50A/div
5μsec/div



COMMUTATION CAPACITOR (C_C)
CURRENT

50A/div
5μsec/div



REVERSE TURN-OFF VOLTAGE
ACROSS THYRISTOR P_{C+}

5V/div
5μsec/div

Figure 25. Power Center Thyristor Turn-Off Circuit with C. T. Transformer

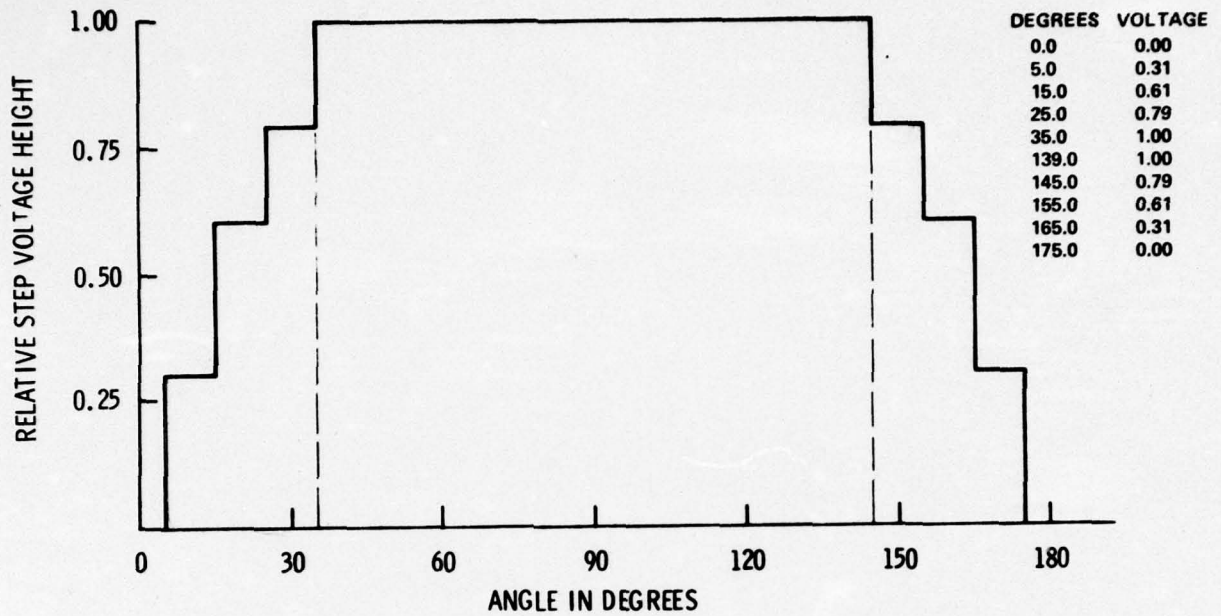


Figure 26. Computer Calculated Waveform Design 110° Wide Power Center, 10° Wide Steps, Zero Dwell Line-to-Neutral THD = 19.14%
Line-to-Line THD = 5.6%

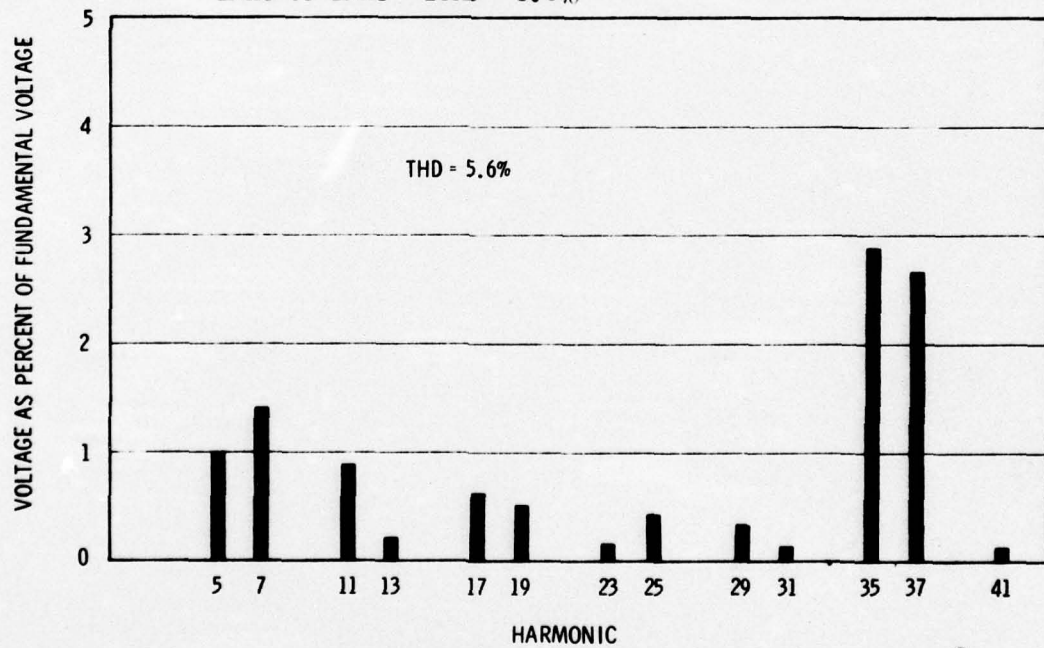


Figure 27. Individual Non-Triplen Harmonics Computed for the 110° Wide Power Center Waveform

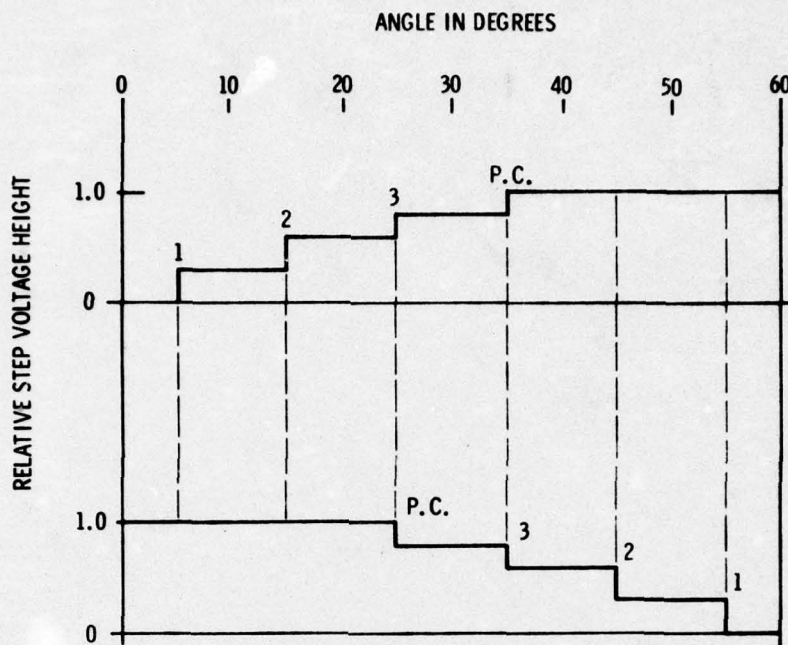


Figure 28. Step Voltage Relationships Between Two Phases for the 110° Wide Power Center Waveform

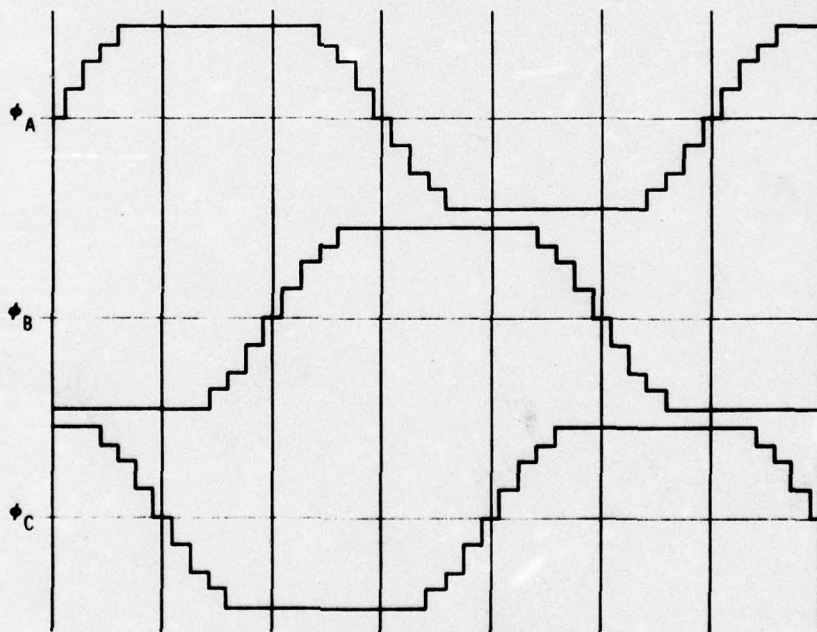


Figure 29. 110° Wide Power Center Wave Three Phase Layout

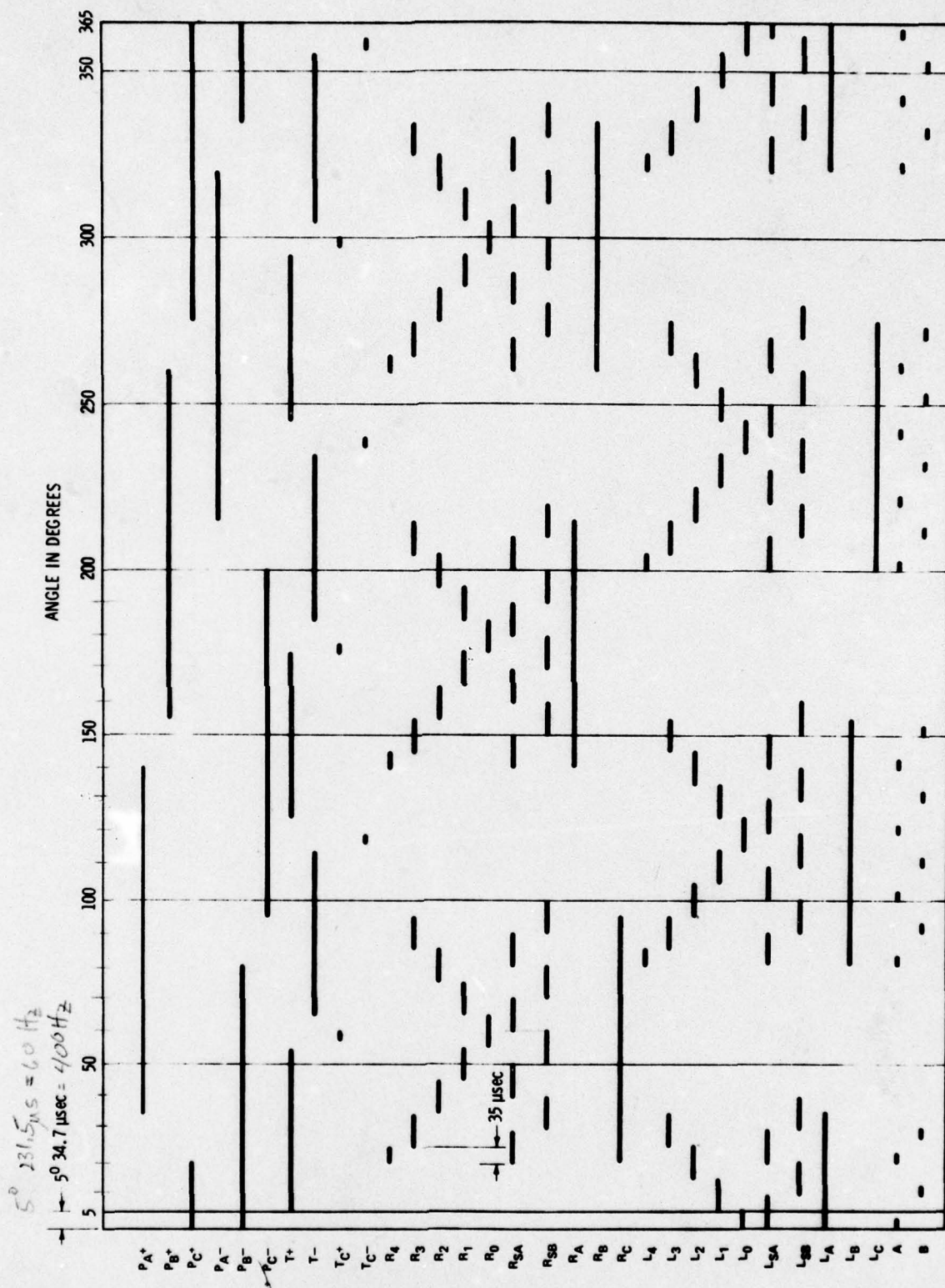


Figure 30. Thyristor Gate Timing Chart for 110° Wide Power Center, 10° Wide Step, Zero Dwell Waveform

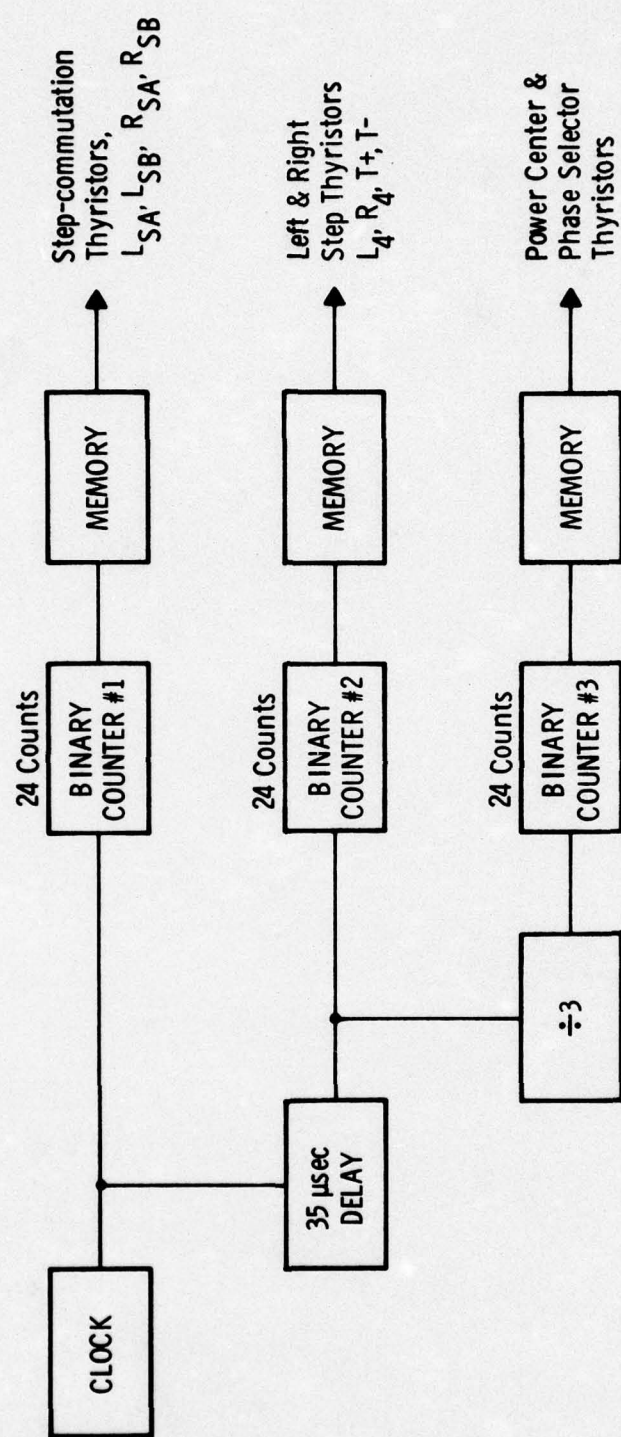


Figure 31. Block Diagram of Memory Timing Circuit

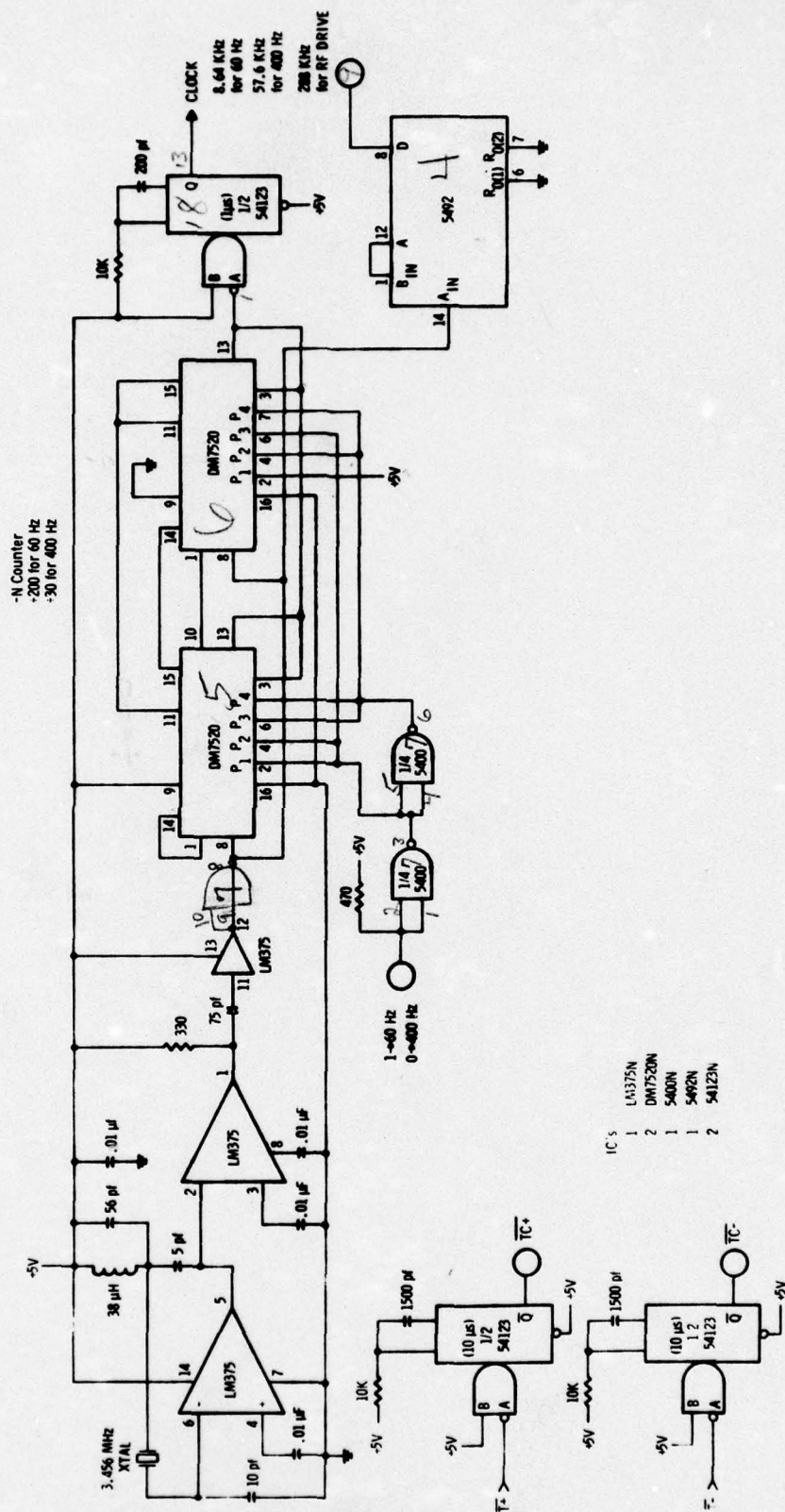


Figure 32a. 110° Wide Power Center Memory Timing Circuit

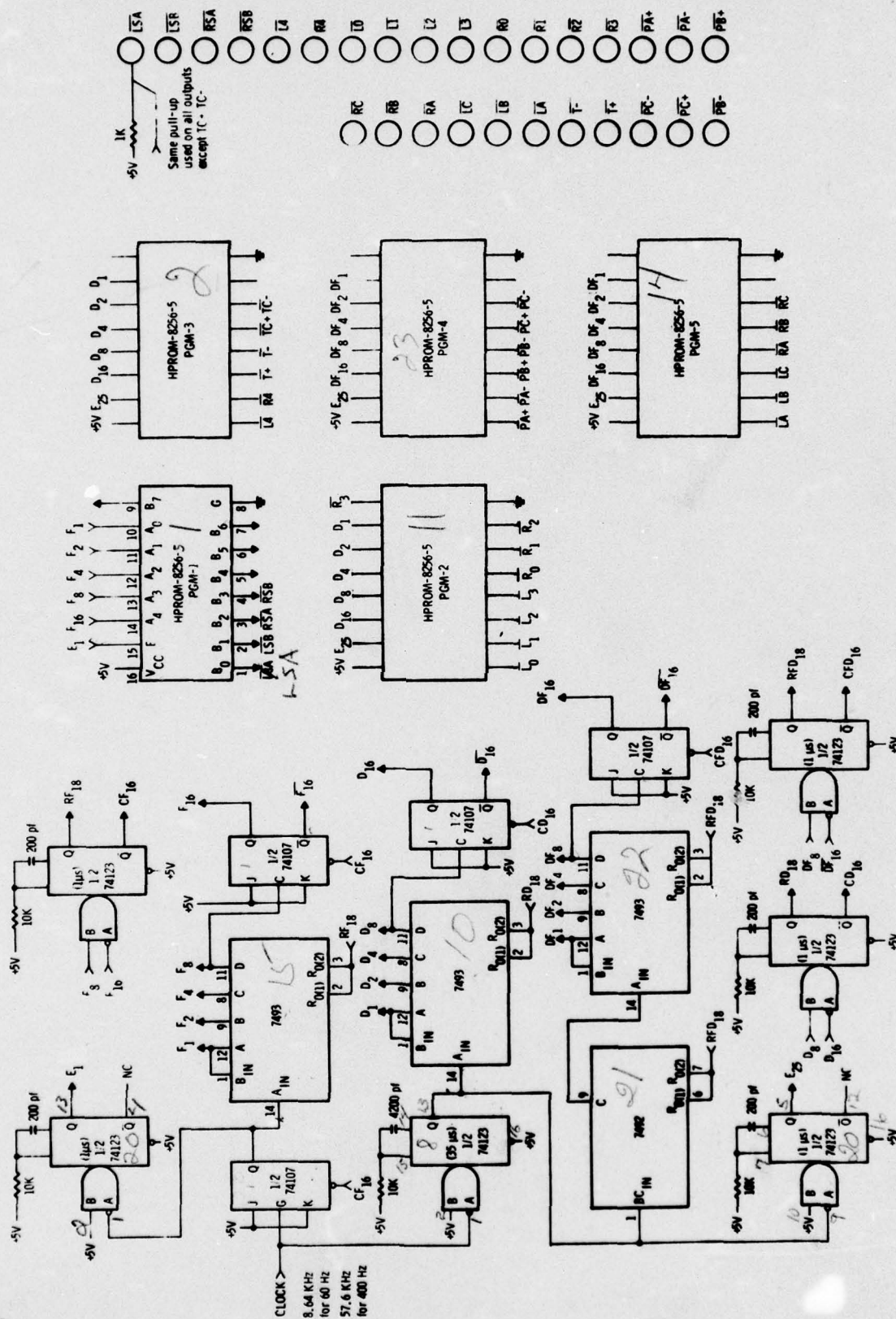


Figure 32b. 110° Wide Power Center Memory Timing Circuit

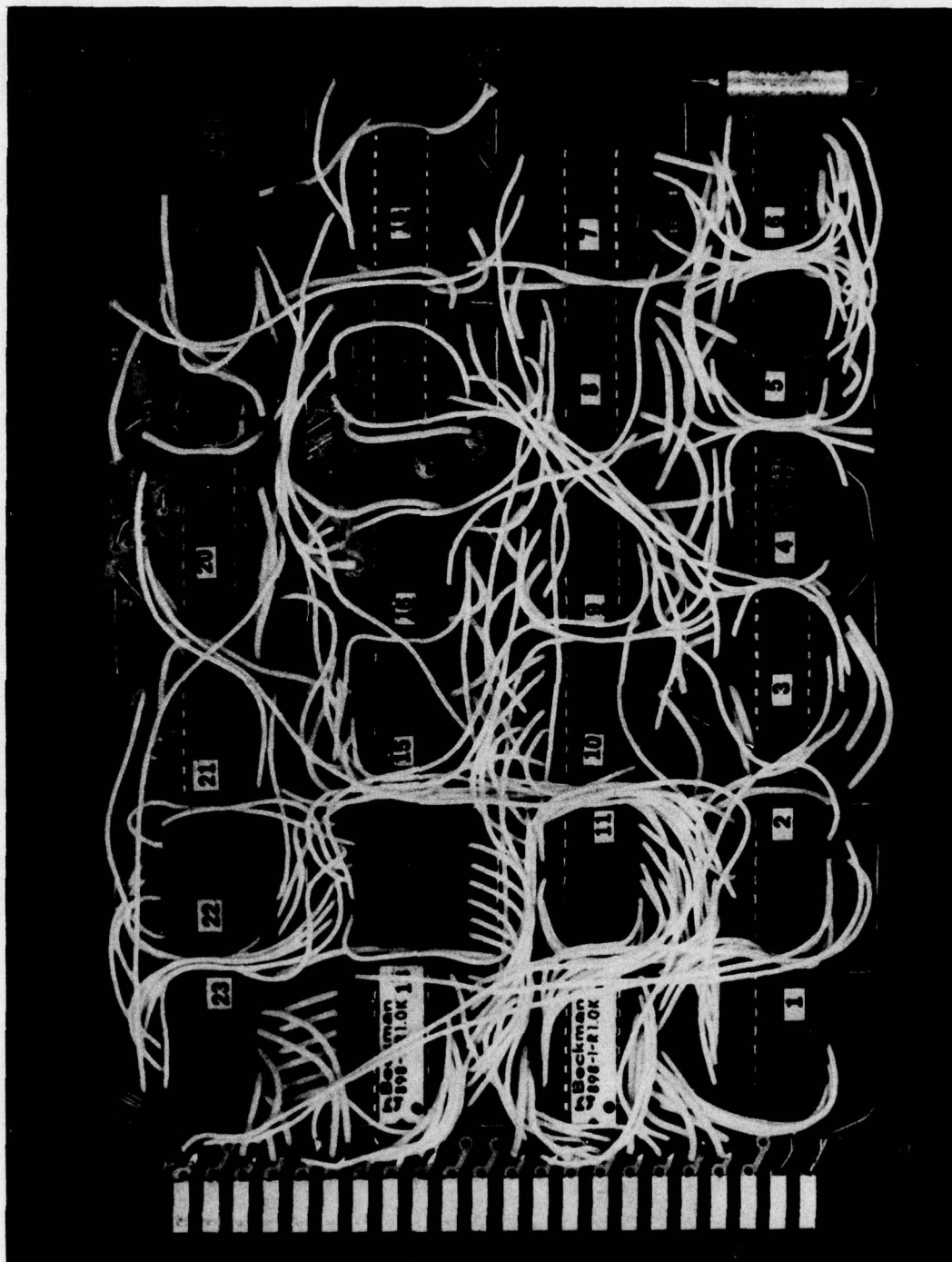


Figure 33. Memory Timing Circuit

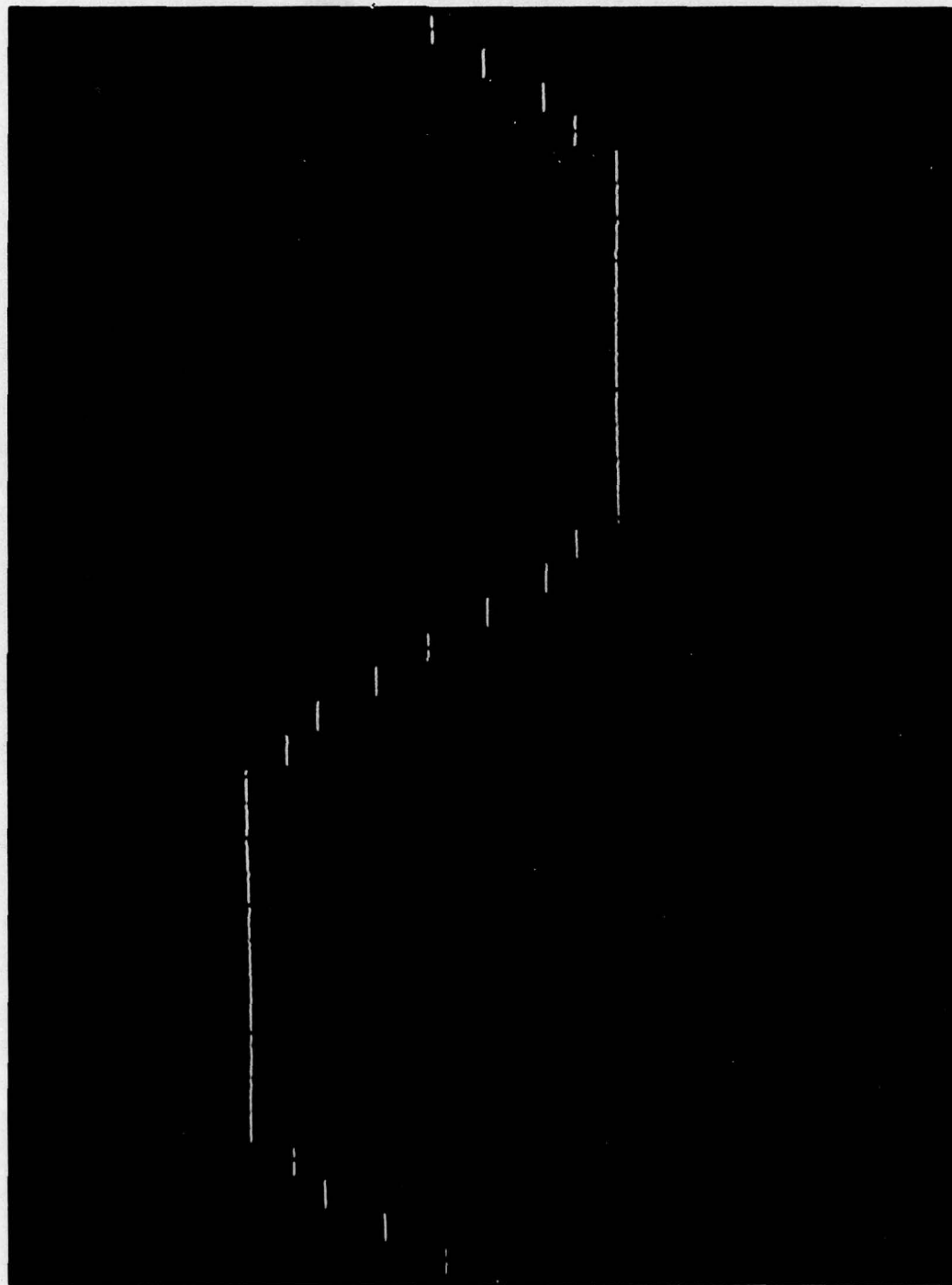


Figure 34. 110° Wide Power Center Line-to-Neutral Voltage
Generated by the Item 0006 Inverter

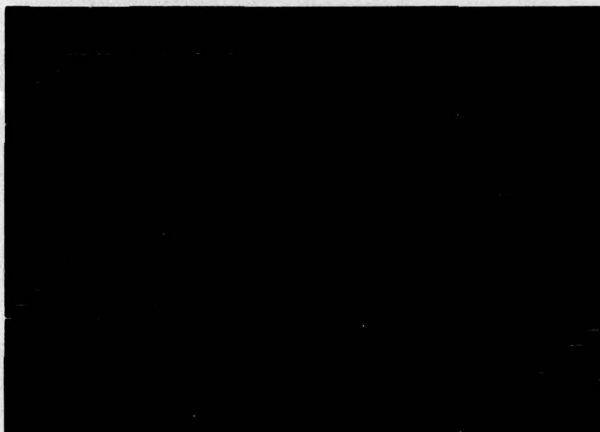


Figure 35. Top Trace: Input to Triplen Attenuator. Bottom Trace: Output of Triplen Attenuator

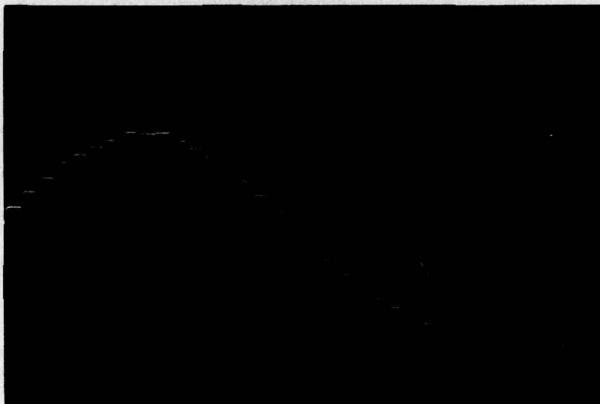


Figure 36. Unfiltered Line-to-Neutral Voltage

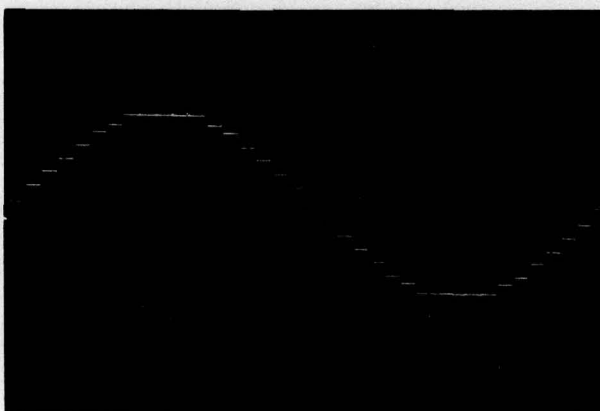


Figure 37. Unfiltered Line-to-Line Voltage

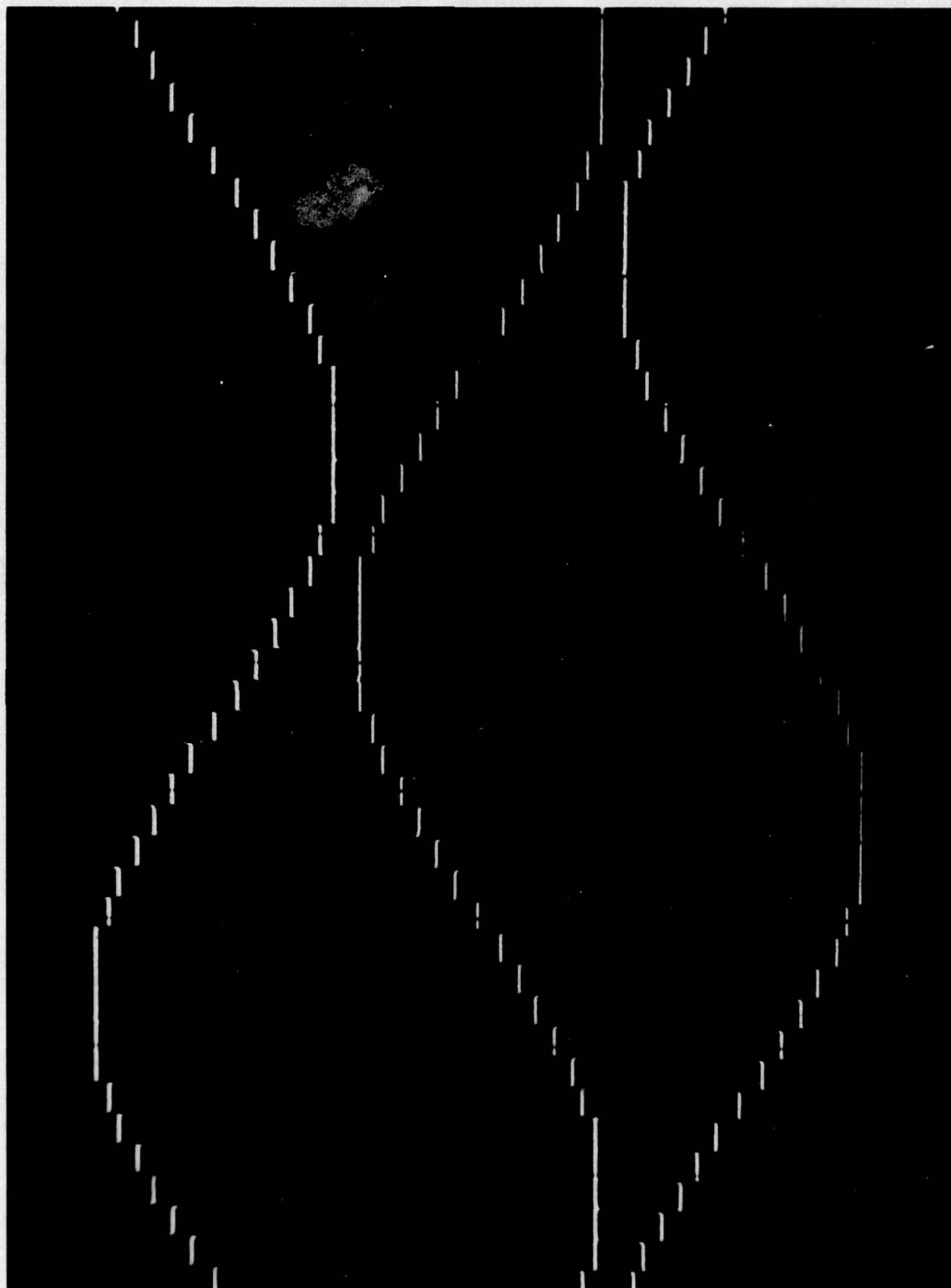


Figure 38. Three Phase Line-to-Line Inverter Output Voltage

APPENDIX A

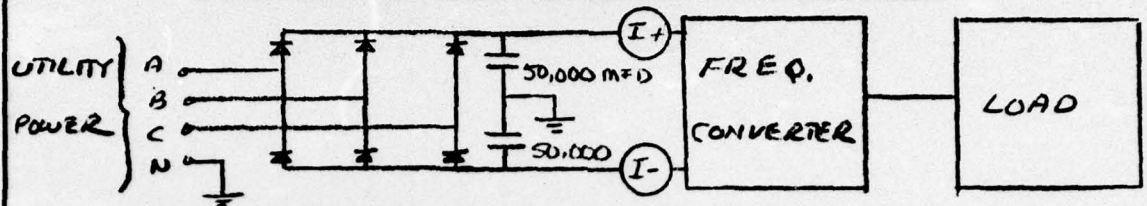
TASK G. DOCUMENTATION OF TECHNICAL DATA

APPENDIX A

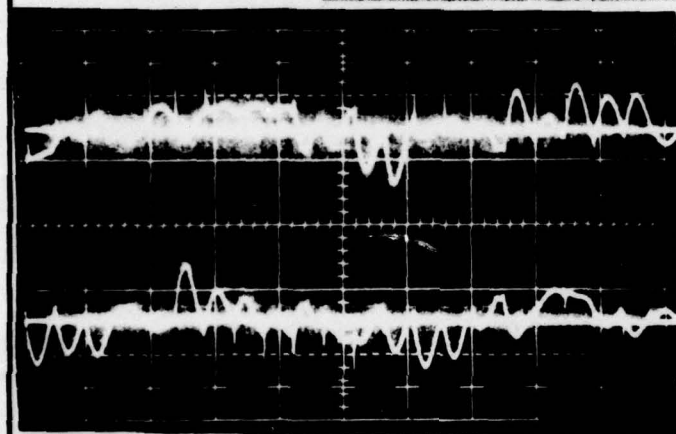
Task g. Documentation of Technical Data

DELCO ELECTRONICS GENERAL MOTORS CORPORATION	REPORT NO. ITEM NO. 0006	PAGE	JOB NO. DESIGN DATA	PAGE 1
	TITLE CIRCUIT DESIGN DATA 15KVA FRE- QUENCY CONVERTER ITEM NO. 0006 CONTRACT NO. DAAK02-72-C-0210		PREPARED CORRY	DATE 11/12/74
		CHECKED		
		APPROVED		

CIRCUIT DESIGN TEST DATA 60HZ



INVERTER INPUT CURRENT - 60HZ 3 PHASE

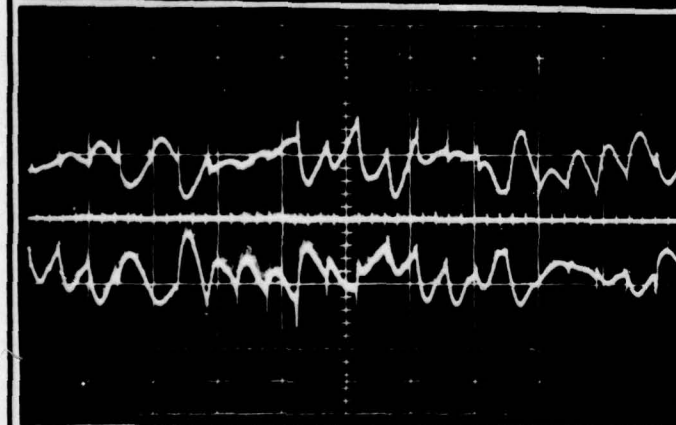


I+

NO LOAD INPUT
CURRENT

50A/DIV.
1ms/DIV

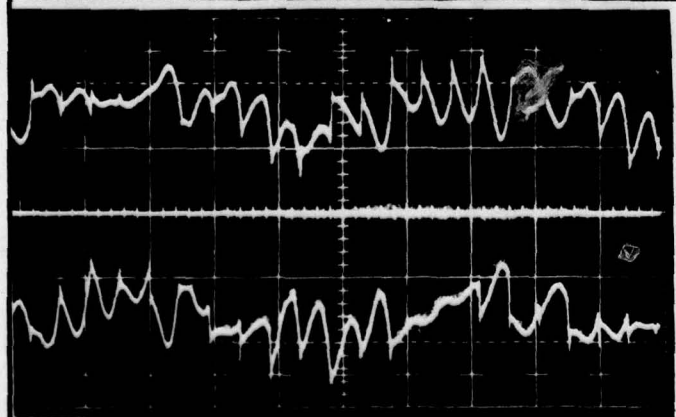
I-



I+

11KW, PF=0.8

I-



I+

20.6 KW, PF=0.8

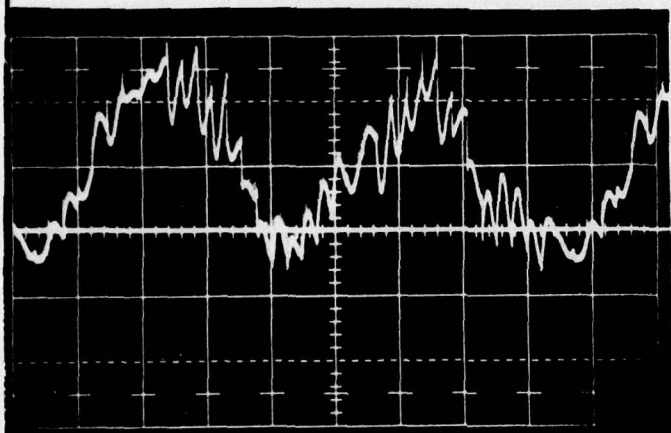
I-

I-

DISTRIBUTION:

DELCO ELECTRONICS GENERAL MOTORS CORPORATION	REPORT NO. ITEM NO. 0006	PAGE DESIGN DATA	JOB NO. 2
	TITLE		
PREPARED CORRY		DATE 11/12/79	
CHECKED		APPROVED	

INVERTER DC INPUT CURRENT - 60HZ SINGLE PHASE

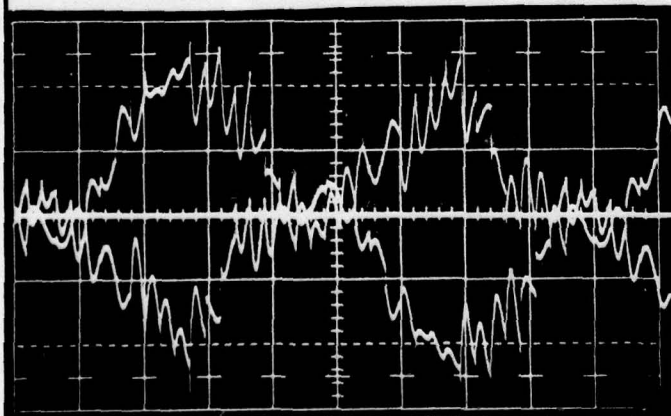


I_+

10KW, PF = 0.8

50A / DIV.

2ms / DIV.



I_+

10KW, PF = 0.8

I_-

DISTRIBUTION:

TITLE

PREPARED

'CORR'

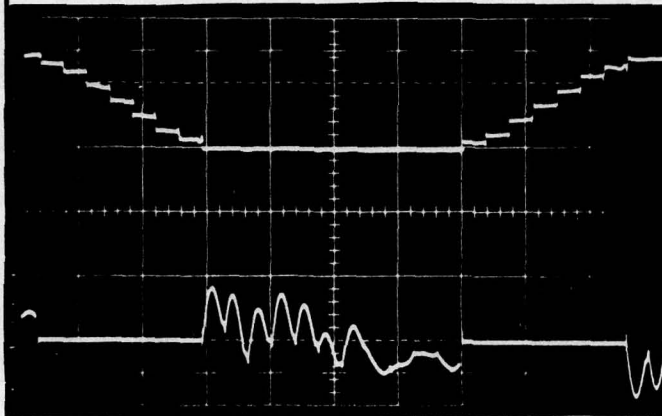
DATE

11/12/74

CHECKED

APPROVED

POWER CENTER THYRISTOR VOLTAGES AND CURRENTS
60HZ, THREE PHASE

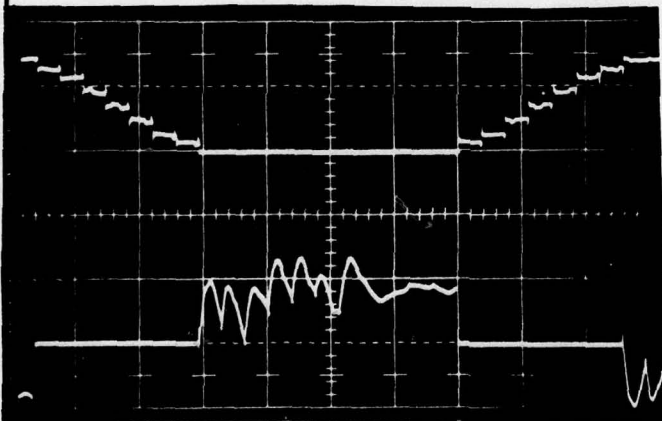


POWER CENTER
THYRISTOR VOLTAGE

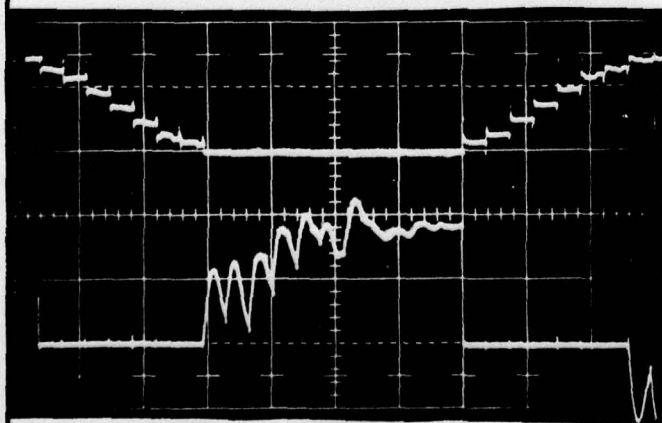
200 V/DIV.

NO LOAD

THYRISTOR & DIODE CURRENT
50 A/DIV.



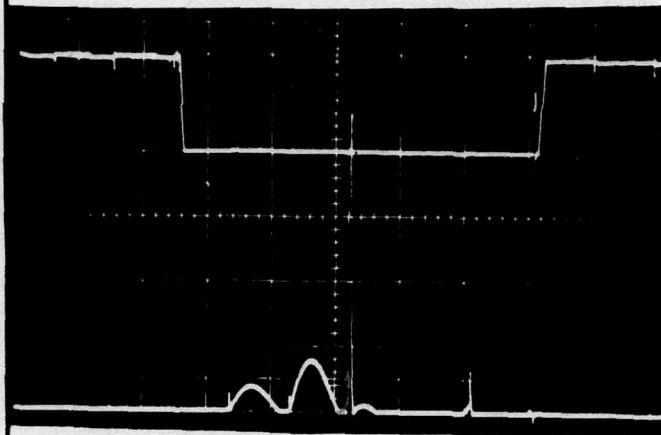
11KW, PF=0.8



20.6 KW, PF=0.8

DISTRIBUTION:

DELCO ELECTRONICS GENERAL MOTORS CORPORATION	REPORT NO. ITEM NO. 0006	PAGE JOB NO. DESIGN DATA	PAGE 4
	PREPARED CORRY		DATE 11/12/79
TITLE		CHECKED	
		APPROVED	



T- THYRISTOR VOLTAGE

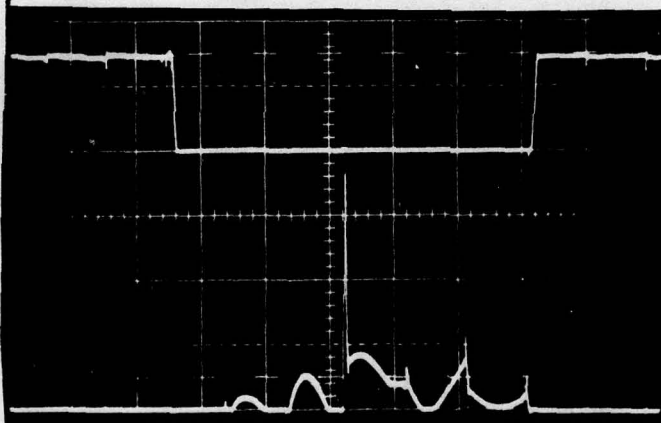
200V / DIV.

NO LOAD

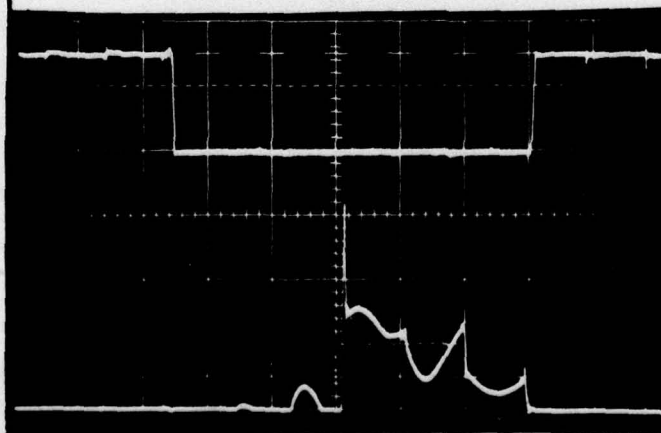
T- CURRENT

50A / DIV.

0.5MS / DIV.



11KW, PF=0.8

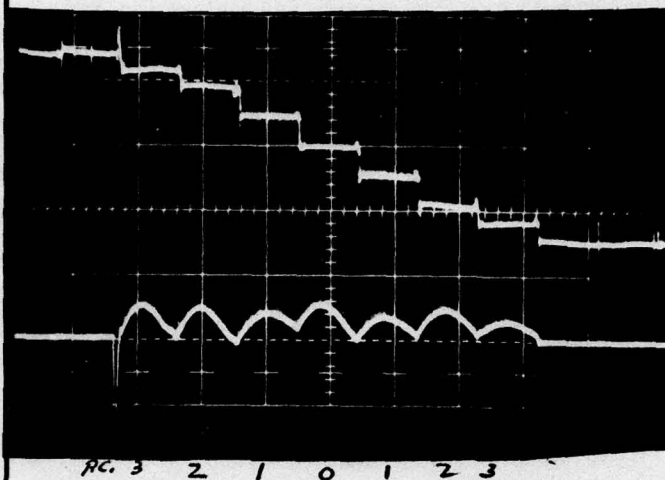


20.6KW, PF=0.8

DISTRIBUTION:

DELCO ELECTRONICS GENERAL MOTORS CORPORATION	REPORT NO. ITEM No 0006	PAGE JOB NO. DESIGN DATA	PAGE 5
	TITLE		PREPARED CORRY 11/12/74 CHECKED APPROVED

STEP VOLTAGES AND CURRENTS - 60HZ, THREE PHASE



LEFT SIDE STEP
VOLTAGE

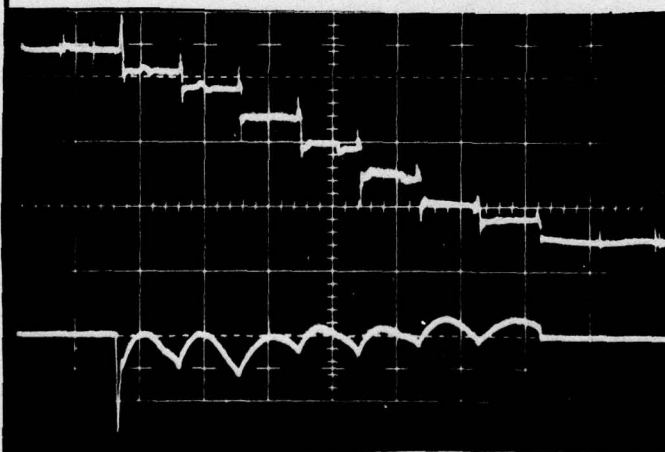
100V/DIV.

NO LOAD

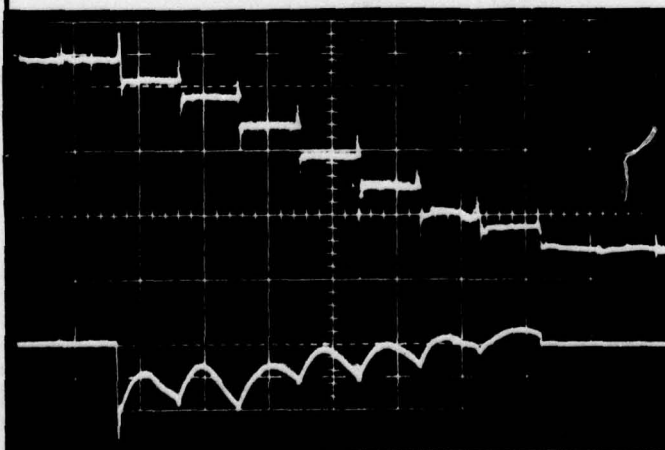
STEP CURRENT

100A/DIV.

0.5MS/DIV.



11KW, PF=0.8

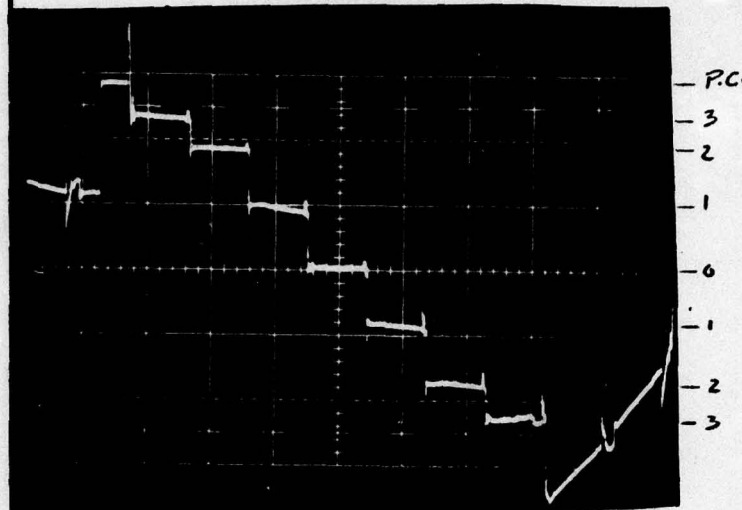


20.6 KW, PF=0.8

DISTRIBUTION:

DELCO ELECTRONICS GENERAL MOTORS CORPORATION	REPORT NO. ITEM NO. 0006	PAGE 6	JOB NO. DESIGN DATA	PAGE 6
	TITLE		PREPARED CORY	DATE 11/12/74
		CHECKED		
		APPROVED		

AUTOTRANSFORMER STEP VOLTAGES 60 HZ, 3 PHASE

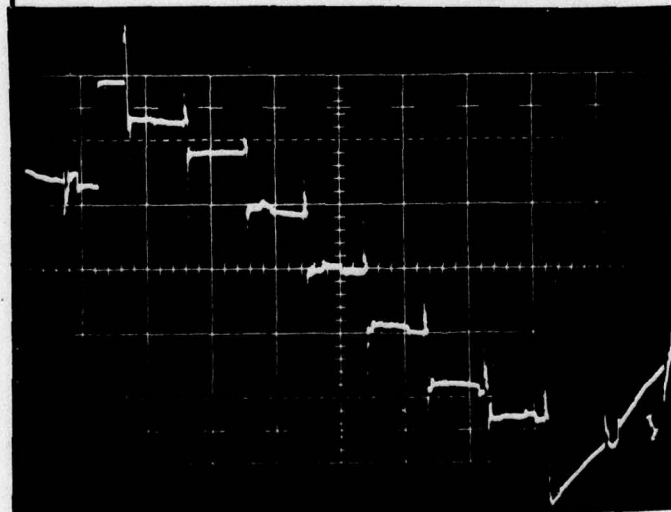


Y STEP FUNCTION

NO LOAD

50V / DIV.

0.5 MS / DIV.



11 KW, PF=0.8

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.
ITEM NO.
0006

PAGE JOB NO.
DESIGN
DATA

PAGE
7

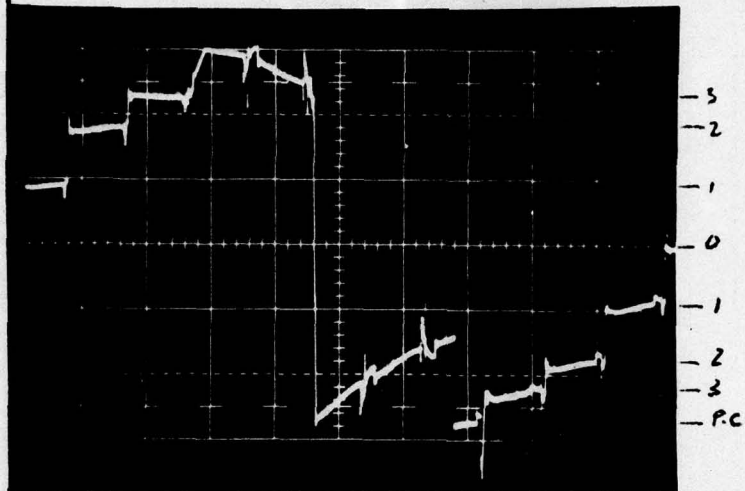
TITLE

PREPARED CORRY 11/12/74 DATE

CHECKED

APPROVED

AUTOTRANSFORMER STEP VOLTAGES 60 HZ, 3 PHASE

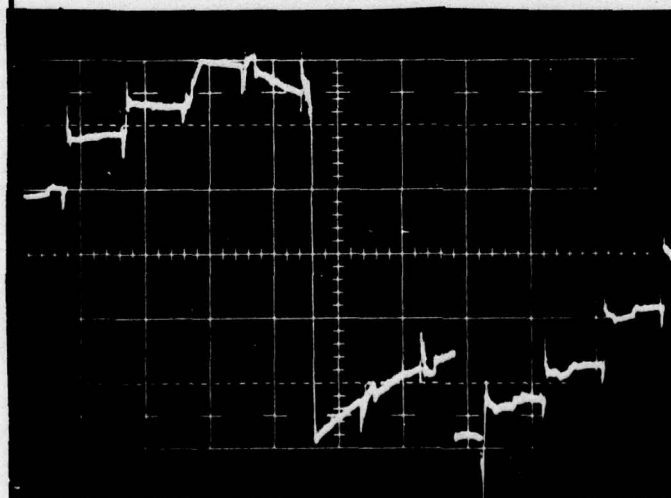


X STEP FUNCTION

NO LOAD

50V/DIV.

0.5MS/DIV.



11KW, PF=0.8

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

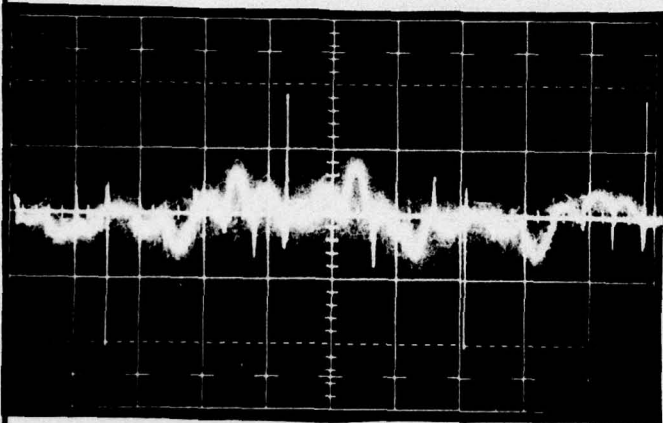
REPORT NO.
ITEM NO.
0006PAGE
JOB NO.
DESIGN
DATAPAGE
8

TITLE

PREPARED
CORRY
DATE
11/12/74

CHECKED

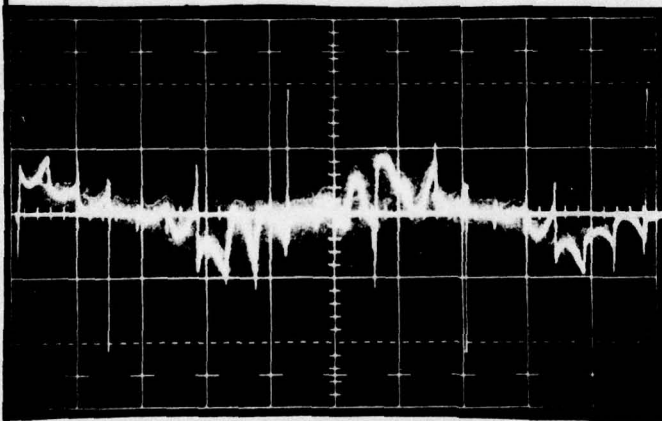
APPROVED

STEP TRANSFORMER CURRENT 60HZ, THREE PHASE

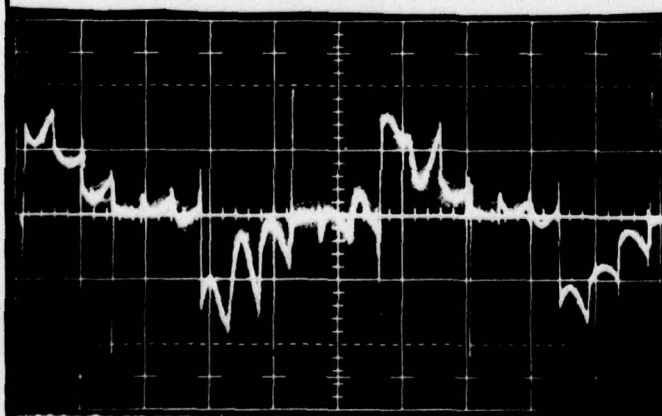
NO LOAD

50 A/DIV.

1MS/DIV.



11KW, PF=0.8



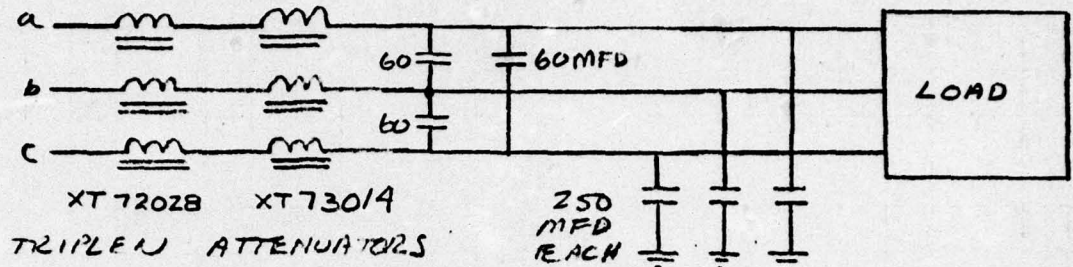
20.6 KW, PF=0.8

DISTRIBUTION:

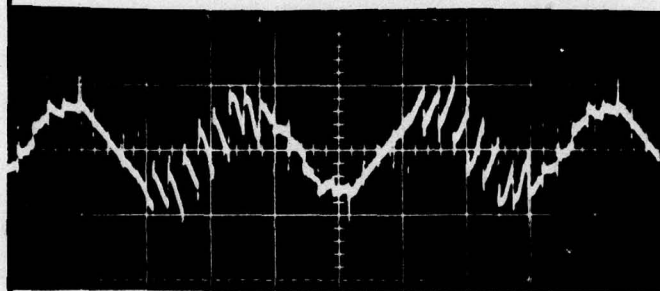
TITLE

PREPARED CORRY
CHECKED
APPROVED
DATE 11/12/74

VOLTAGE DROPS ACROSS TRIPLEN ATTENUATORS-60HZ, 3 PHASE



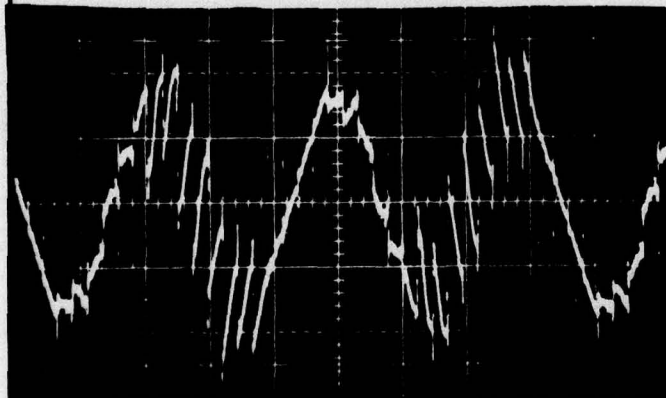
OUTPUT FILTER CIRCUIT



VOLTAGE DROP ACROSS
BOTH TRIPLEN ATTENUATORS
NO LOAD

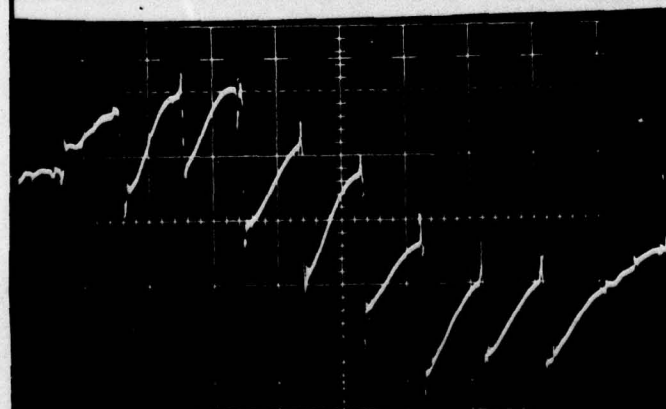
50V/DIV

2ms/DIV.



20V/DIV.

2ms/DIV.

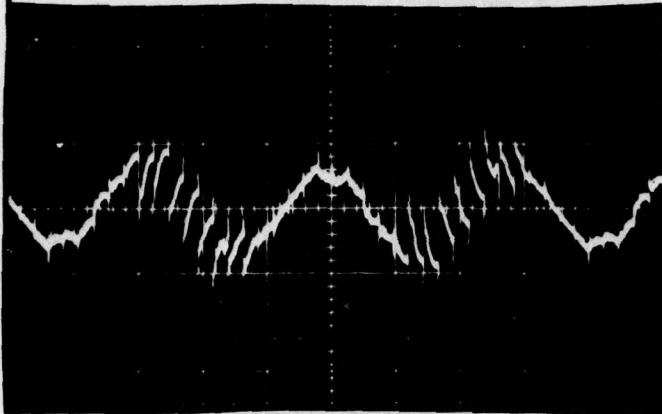


20V/DIV.

500μSEC/DIV.

DISTRIBUTION:

DELCO ELECTRONICS GENERAL MOTORS CORPORATION	REPORT NO. ITEM NO. 0006	PAGE JOB NO. DESIGN DATA	PAGE 10
	TITLE		PREPARED CORY CHECKED APPROVED
		DATE 11/12/79	

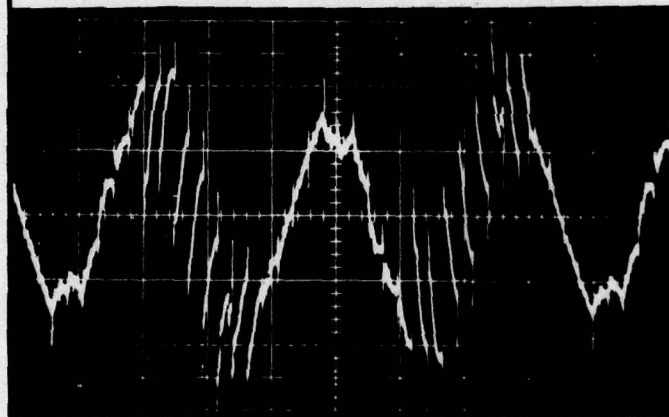


VOLTAGE DROP ACROSS
BOTH TRIPLEN ATTENUATORS

20.6 KW, PF=0.8

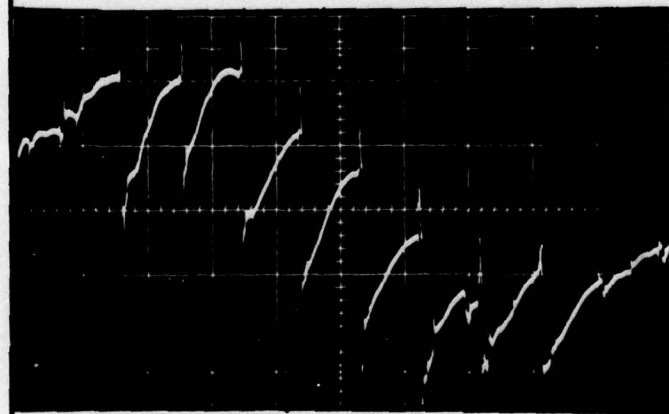
50 V/DIV.

2 MS/DIV.



20 V/DIV.

2 MS/DIV.



20 V/DIV.

500 μSEC/DIV.

DISTRIBUTION:

TITLE

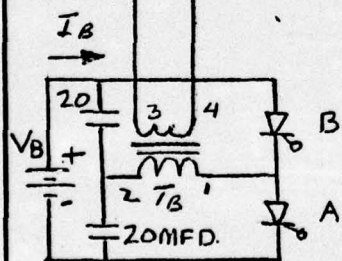
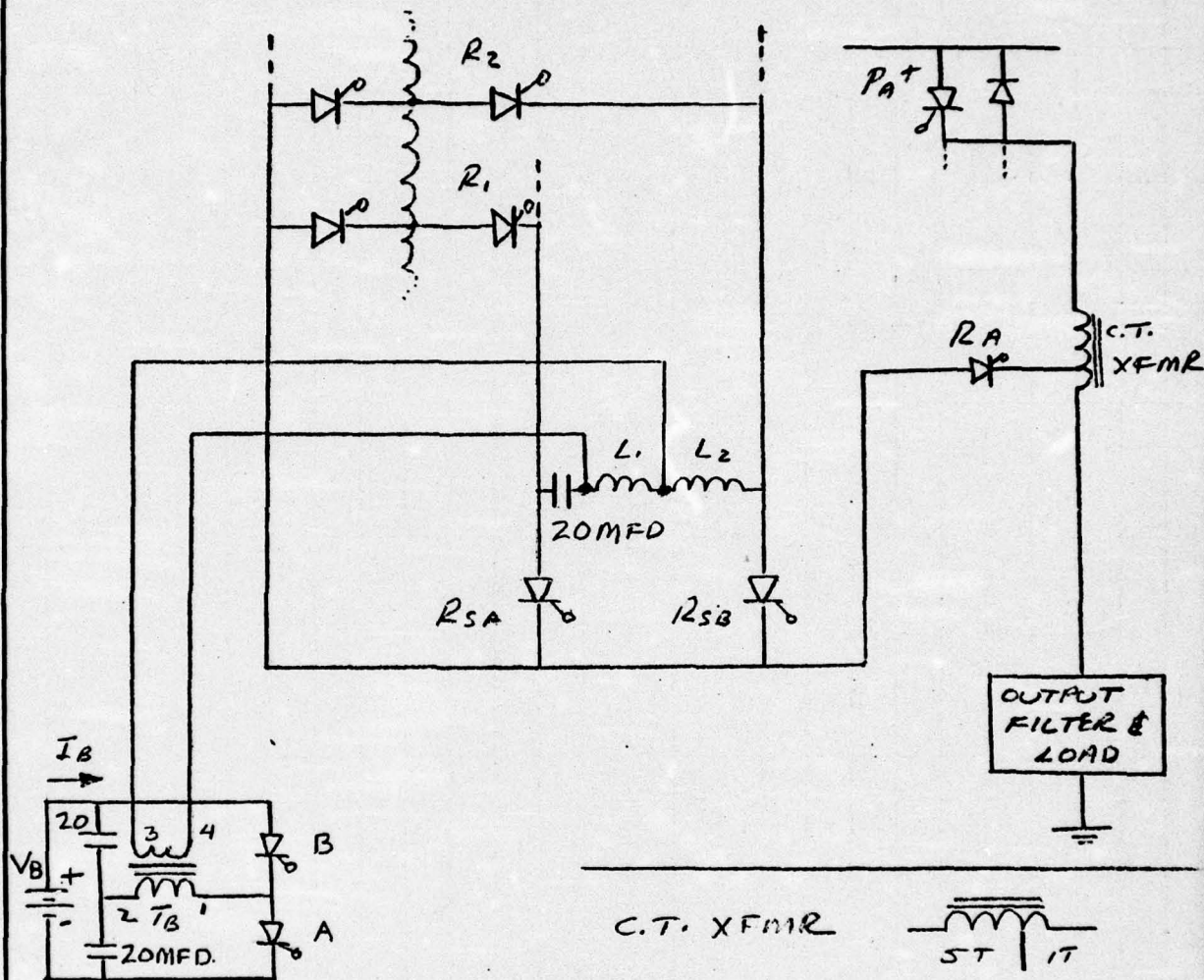
PREPARED

DATE

CHECKED

APPROVED

MEASUREMENTS OF REVERSE BIAS TURN-OFF VOLTAGES FOR INVERTER THYRISTORS - 60 HZ



FOR TURN-OFF
TIME MEASURE-
MENTS $V_B = 66\text{V}$
 $I_B = 9\text{ AMPS}$

C.T. XFMR



G65-55251-A2 COR

 L_1 10 TURNS ON G55-55106-D4 CORE L_2 8 TURNS ON G55-55106-D4 CORE
TWO SETS OF TURNS T_B 20 TURNS PRIMARY
10 TURNS SECONDARY
50001 CORE

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.

0006

PAGE

JOB NO.

DESIGN
DATA

PAGE

11a

TITLE

PREPARED

CORY

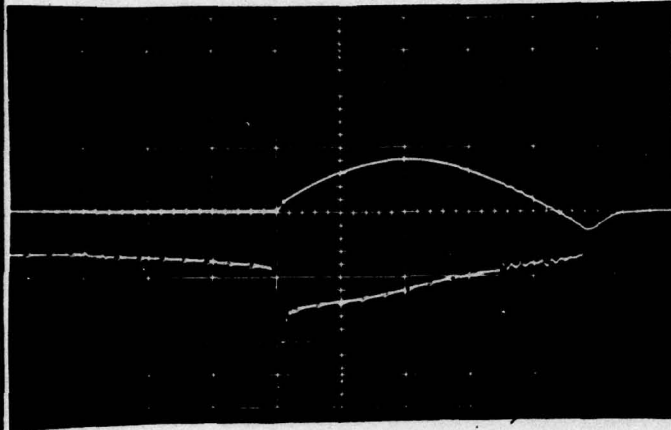
DATE

11/12/79

CHECKED

APPROVED

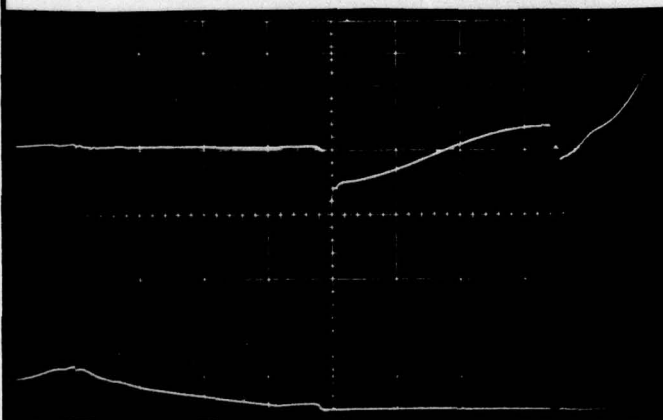
REVERSE BIAS TURN-OFF TIMES .60HZ, THREE PHASE

20.6KW PF=0.8 LOADS PAGES 11-17

POWER CENTER

P₂ TURN OFFBT-PASS DIODE CURRENT
50A/DIV.REVERSE BIAS VOLTAGE
5V/DIV.

5μSEC/DIV.

T- TURN-OFF

REVERSE BIAS VOLTAGE

20V/DIV.

5μSEC/DIV.

ANODE CURRENT

50A/DIV.

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.
ITEM NO.
0006

PAGE JOB NO.
DESIGN
DATA

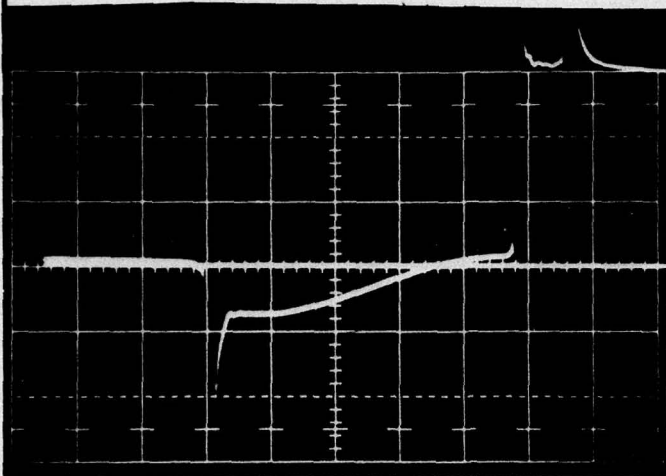
PAGE
12

TITLE

PREPARED CORRY DATE 11/12/79

CHECKED

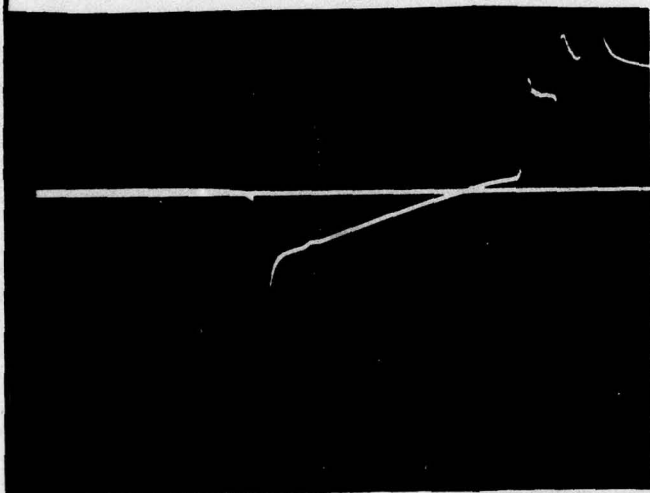
APPROVED



STEP COMMUTATING
THYRISTOR LSB
TURN-OFF

20V/DIV.

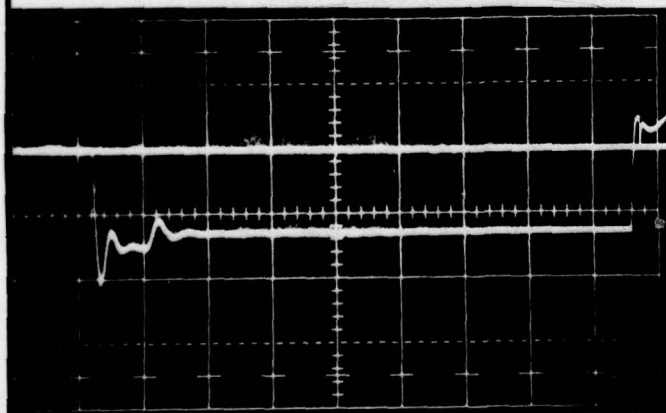
5μSEC/DIV.



STEP COMMUTATING
THYRISTOR LSA
TURN-OFF

20V/DIV.

5μSEC/DIV.



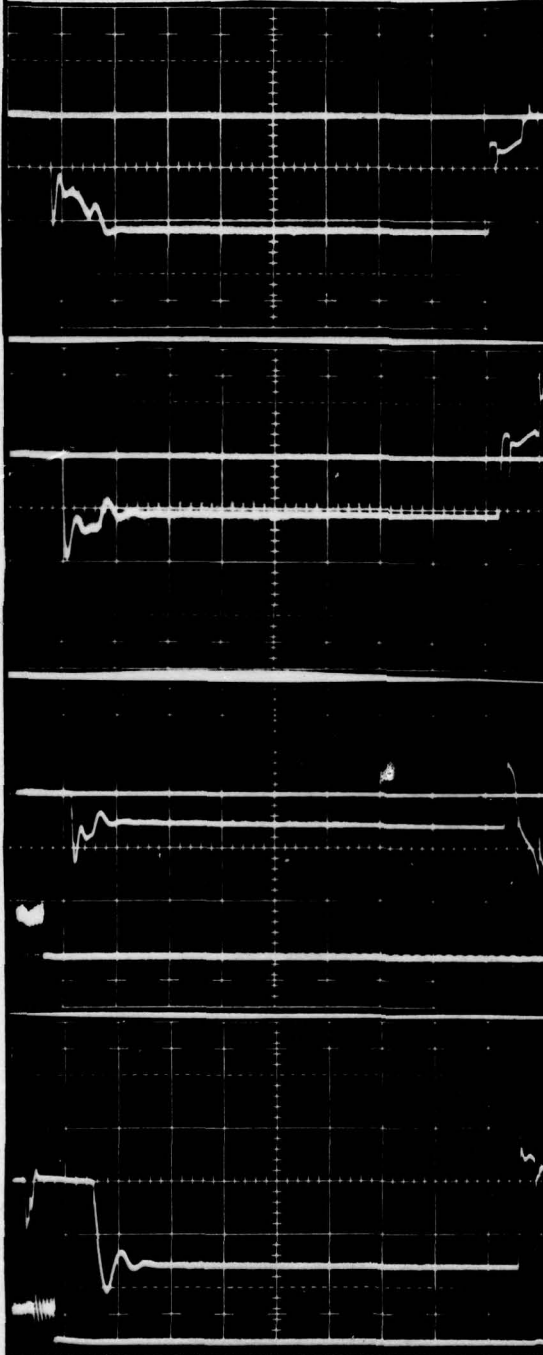
STEP THYRISTOR L0
TURN-OFF

100V/DIV.

50μSEC/DIV.

DISTRIBUTION:

DELCO ELECTRONICS GENERAL MOTORS CORPORATION	REPORT NO. ITEM NO.	PAGE	JOB NO.	PAGE
	0006		DESIGN DATA	13
TITLE	PREPARED	DATE		
	CORRY	11/12/79		
	CHECKED			
APPROVED				



STEP THYRISTOR L₁
TURN-OFF

100V/DIV

50μSEC/DIV.

STEP THYRISTOR L₂
TURN-OFF

STEP THYRISTOR L₃
TURN-OFF

STEP THYRISTOR L₄
TURN-OFF

DISTRIBUTION:

DELCO ELECTRONICS GENERAL MOTORS CORPORATION	REPORT NO. ITEM NO.	PAGE	JOB NO.	PAGE
	0006		DESIGN DATA	27
TITLE	PREPARED	DATE		

TITLE

PREPARED

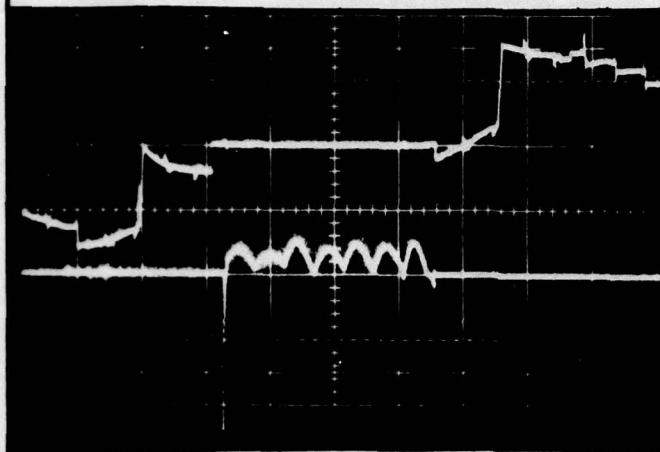
CORRY

DATE

11/12/79

CHECKED

APPROVED

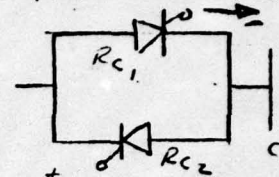
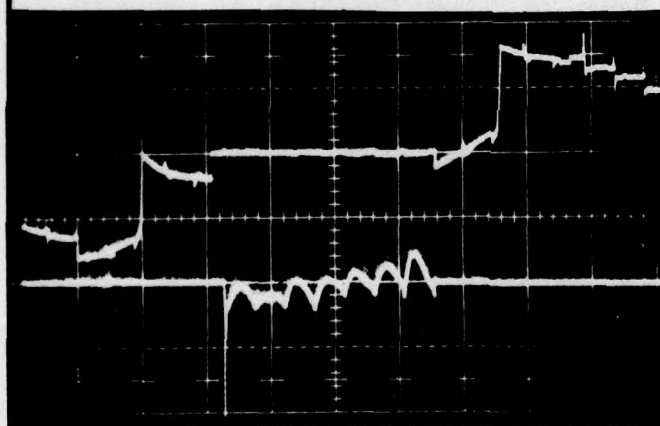
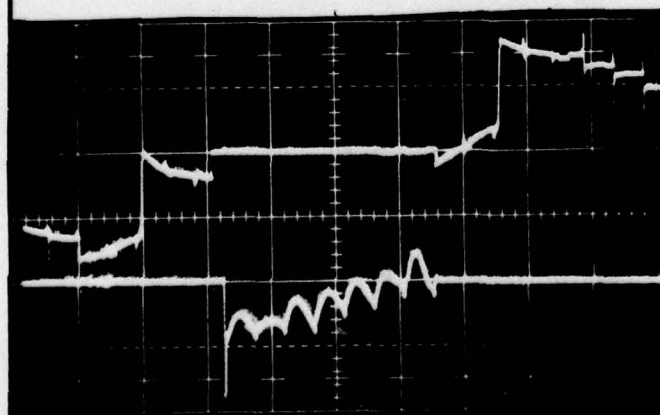
PHASE SELECTOR R_C
TURN-OFF

200V/DIV.

100A/DIV.

1ms/DIV.

P.C. TURN-OFF PULSE

NO LOAD
CURRENTP.F. CORRECTED
BOTTOM SCR
REV. BIASED
WHEN P_C^- TURNS
ON11KW, $PF=0.8$ 20.6 KW, $PF=0.8$ REVERSED BIASED FOR 400
μSEC. WHEN P_C^- TURNS-ONFOR LOW P.F. LAGGING
LOADS (NEG. CURRENT)
TOP SCR STARVES OFF.

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.

0006

PAGE

JOB NO.

DESIGN

DATA

PAGE

15

TITLE

PREPARED

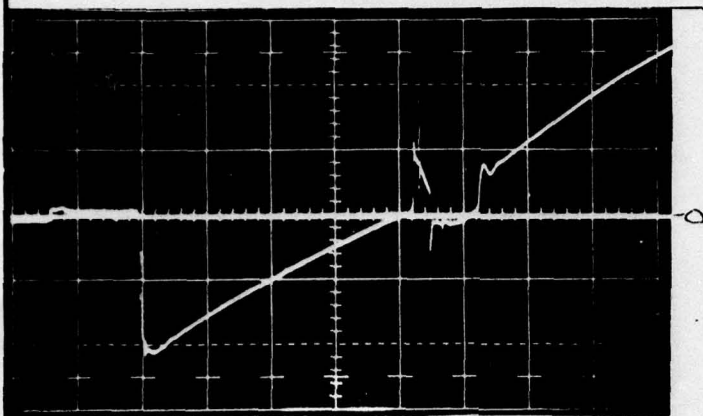
CORRY

DATE

11/12/74

CHECKED

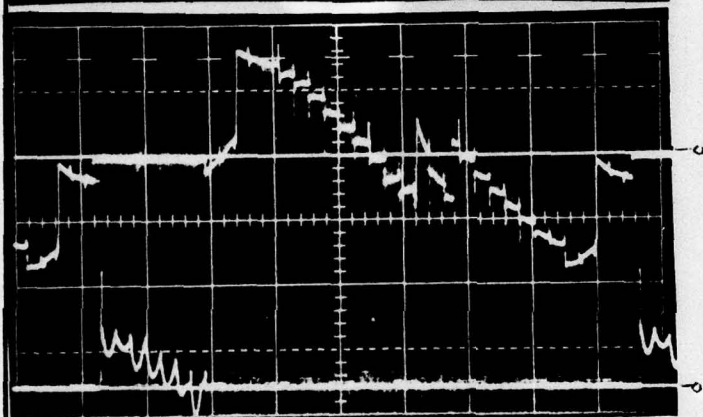
APPROVED



R_C REVERSE BIAS
VOLTAGE

20V/DIV.

100 μ SEC/DIV.

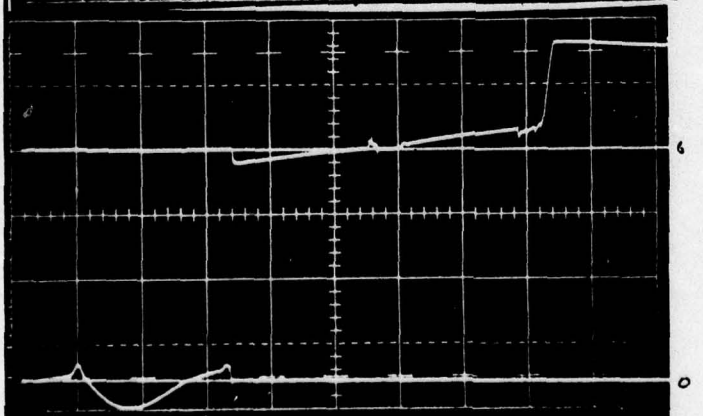


200V/DIV.

2ms/DIV.

CURRENT THRU R_C

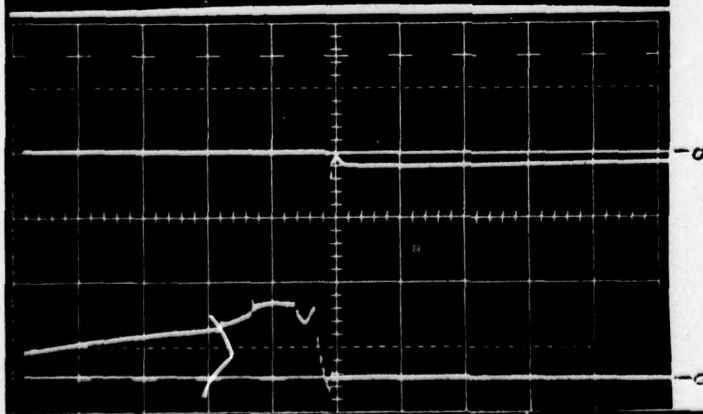
100A/DIV.



VOLTAGE

200V/DIV.

200 μ SEC/DIV.



CURRENT

100A/DIV.

VOLTAGE

200V/DIV.

20 μ SEC/DIV.

CURRENT

100A/DIV.

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.

0006

PAGE

JOB NO.

DESIGN

DATA

PAGE

16

TITLE

PREPARED

CORRY

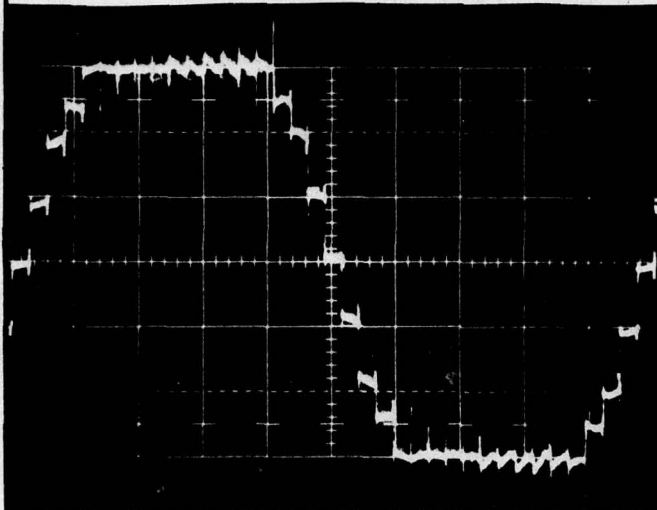
DATE

11/15/74

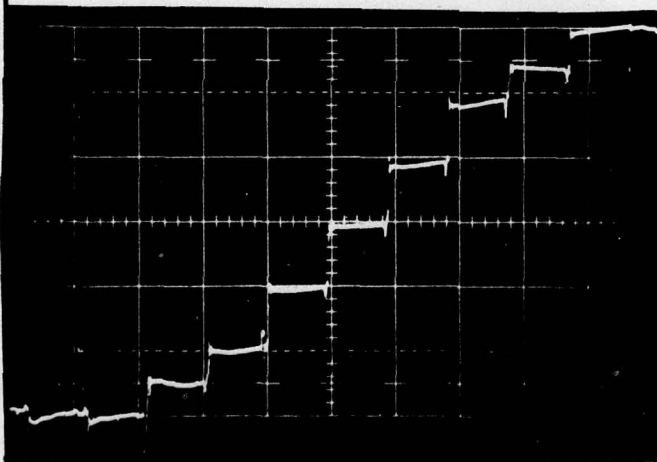
CHECKED

APPROVED

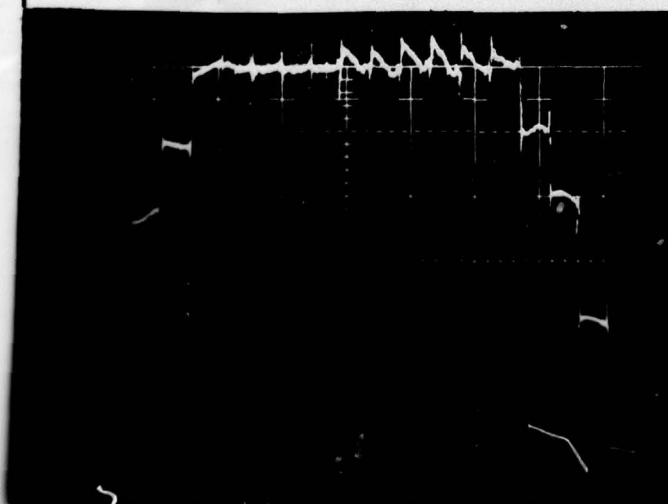
INVERTER BASIC VOLTAGES 60HZ NO LOAD



V_{c-n}



0.5 ms/div.



1 ms/div.

TITLE

PREPARED

CORRY

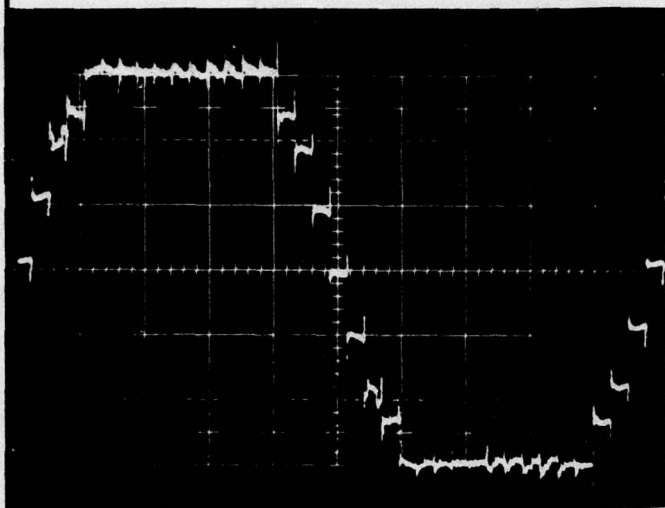
DATE

11/15/74

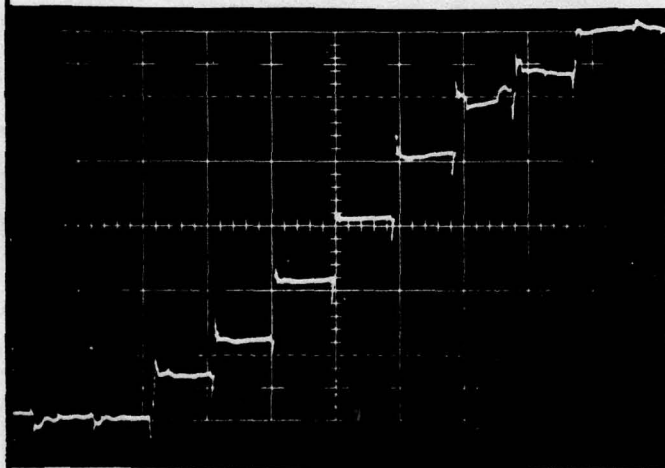
CHECKED

APPROVED

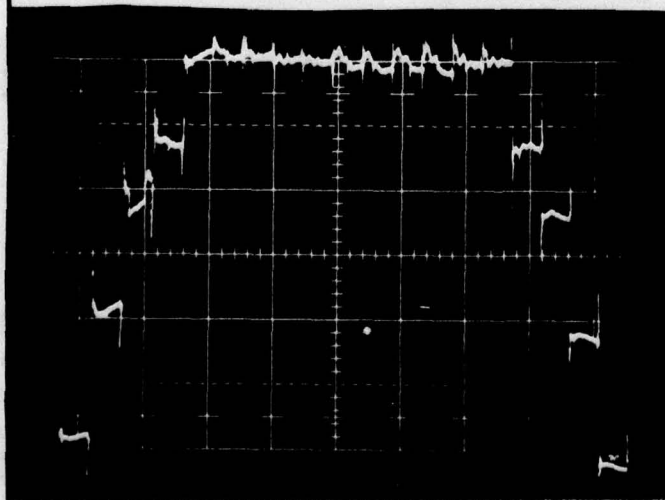
INVERTER BASIC VOLTAGES 60HZ 20.6KW, PF=0.8



V_{c-n}



0.5 ms/DIV.



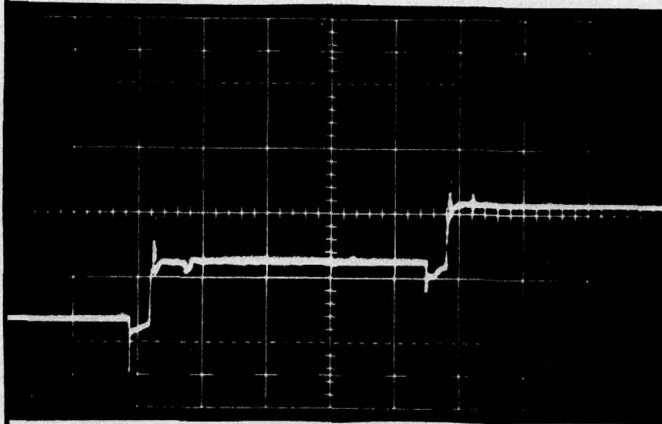
1 ms/DIV.

DISTRIBUTION:

TITLE

PREPARED
CORRY 11/15/74
CHECKED
APPROVED

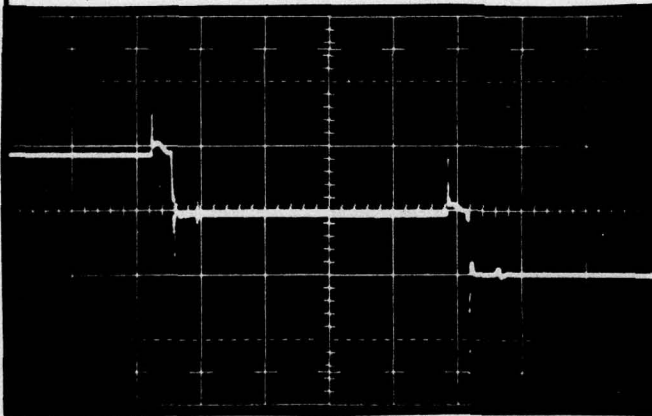
INVERTER BASIC VOLTAGES 60HZ NO LOAD



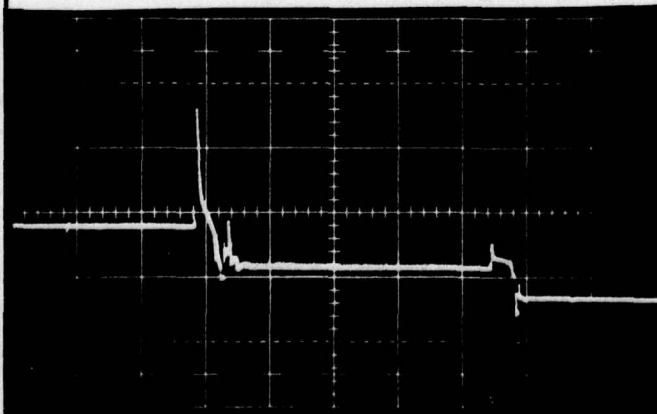
ASCENDING STEPS
2, 1, 0

50V/DIV.

100μSEC/DIV.



DESCENDING STEPS
1, 0, 1



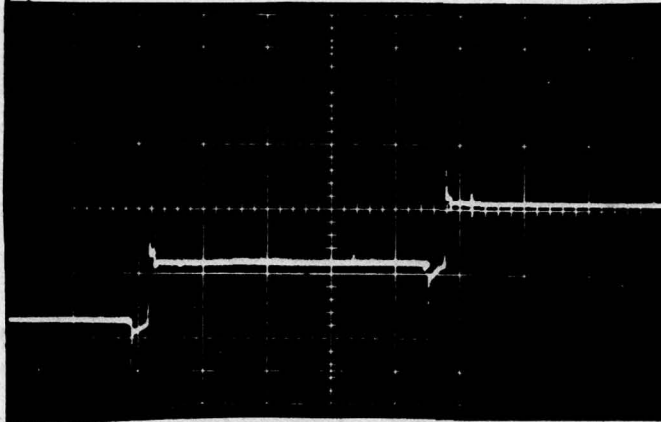
POWER CENTER AND
STEPS 3, 2

DISTRIBUTION:

TITLE

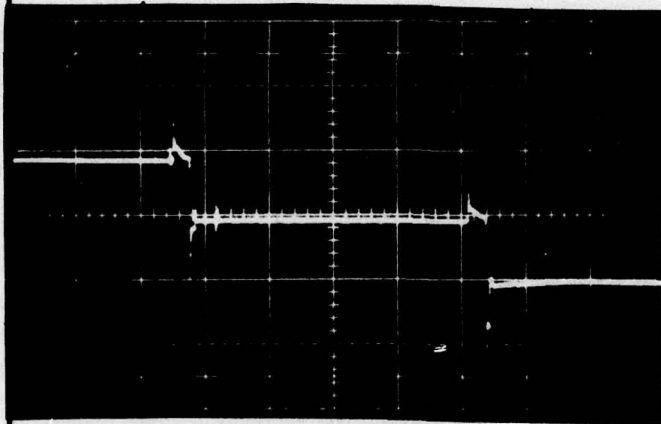
PREPARED
CORRY
DATE
11/15/74
CHECKED
APPROVED

INVERTER BASIC VOLTAGES 60Hz 16KW, PF=0.8

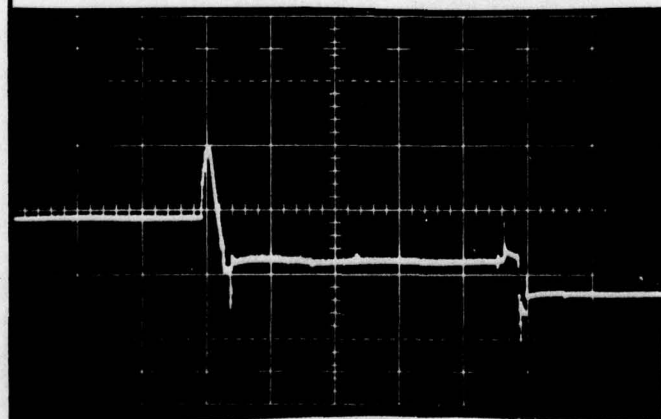


ASCENDING STEPS
2, 1, 0
50V/DIV.

100μSEC/DIV.



DESCENDING STEPS
1, 0, 1



POWER CENTER AND
STEPS 3, 2

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

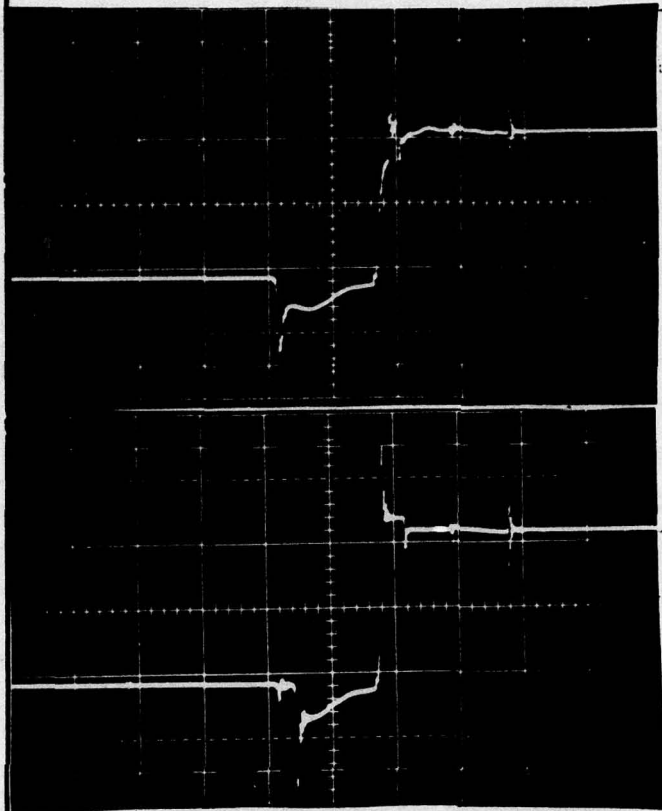
REPORT NO.
ITEM NO.
0006

PAGE JOB NO.
DESIGN
DATA

PAGE
20

TITLE

PREPARED CORRY DATE 11/15/74
CHECKED
APPROVED



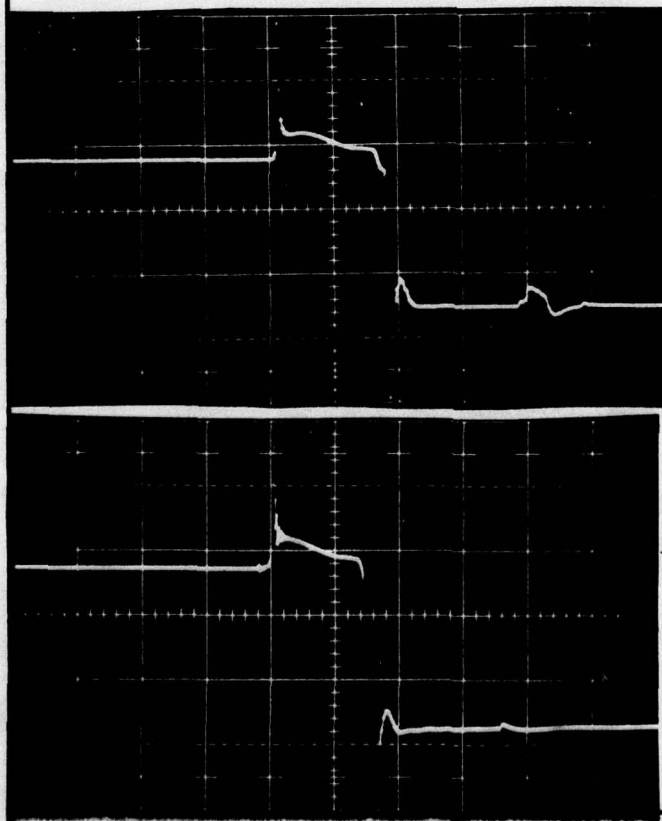
ASCENDING

20V / DIV.

20 μSEC / DIV.

NO LOAD

16KW, PF=0.8



DESCENDING

NO LOAD

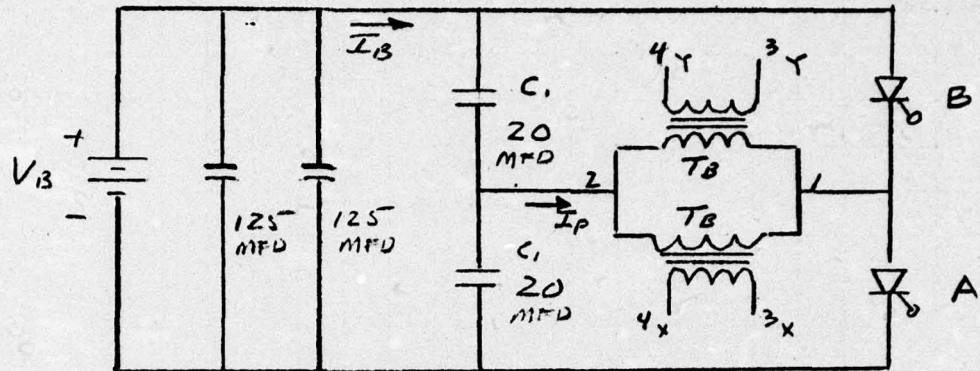
16KW, PF=0.8

DISTRIBUTION:

TITLE

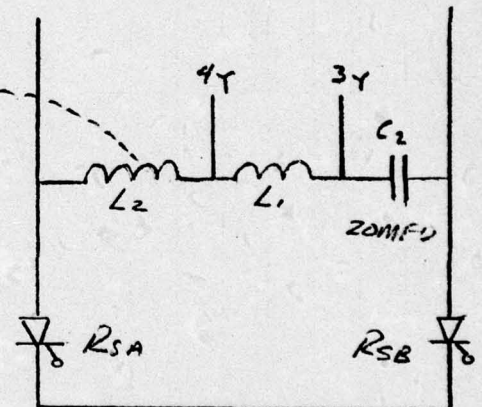
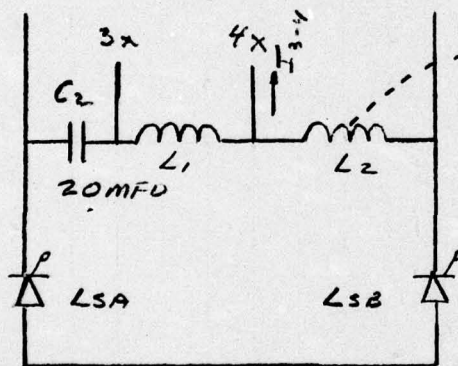
PREPARED GORRY 11/15/74
CHECKED
APPROVED

COMMUTATION BOOST CIRCUIT VOLTAGE
AND CURRENT WAVEFORMS
(60 HZ OPERATION)



X STEPS

Y STEPS



	V_{RMS}	I_{RMS}
C_1	100	32
C_2	135	50

$$V_B = 66 \text{ VDC}$$

$$I_B = 9 \text{ AMPS DC}$$

$$V_{3-4} = 14.2 \text{ V RMS}$$

$$I_{3-4} = 67 \text{ A RMS}$$

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.

0006

PAGE

JOB NO.

DESIGN

DATA

PAGE

22

TITLE

PREPARED

CORY

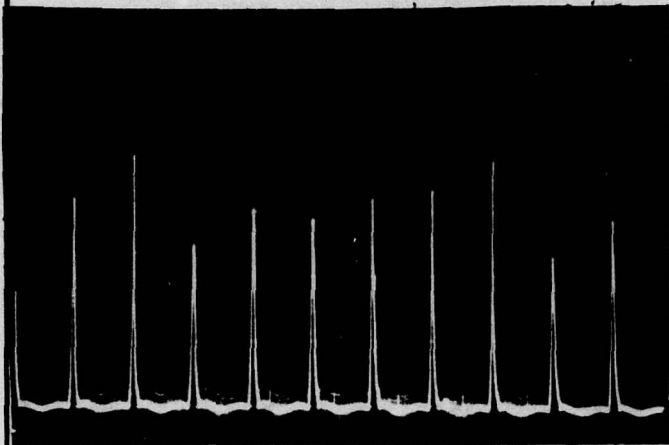
DATE

11/15/74

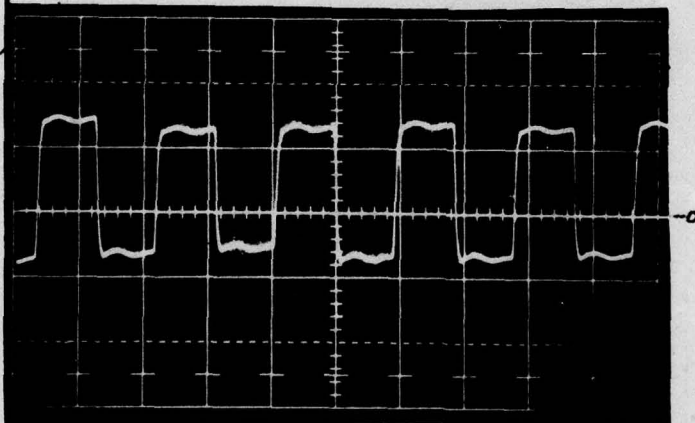
CHECKED

APPROVED

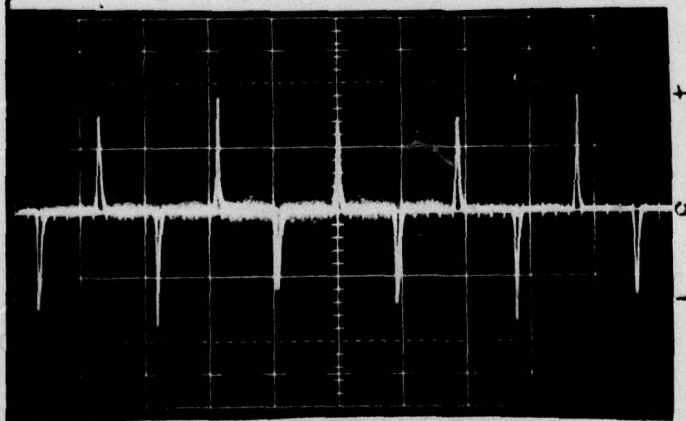
COMMUTATION BOOST CIRCUIT VOLTAGE
AND CURRENT WAVEFORMS

 I_B

50 A/DIV.

500 μ SEC/DIV.VOLTAGE ACROSS
A C, CAPACITOR

100V/DIV.

500 μ SEC/DIV.CURRENT INTO
PRIMARIES OF
TRANSFORMERS T_B 200 A/DIV. 500 μ SEC/DIV.B CURRENTS \uparrow
A CURRENTS \downarrow

DISTRIBUTION:

DELCO ELECTRONICS GENERAL MOTORS CORPORATION	REPORT NO. ITEM NO. 0006	PAGE	JOB NO. DESIGN DATA	PAGE 23
	TITLE		PREPARED CORY 11/15/74	DATE
		CHECKED		
		APPROVED		

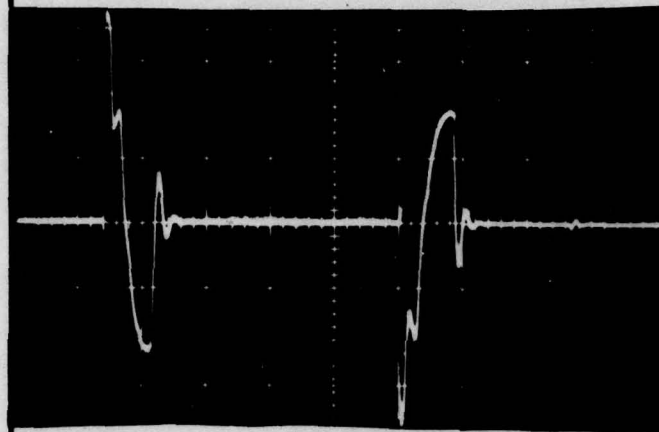
BOOST CIRCUIT WAVEFORMS



VOLTAGE ACROSS L₁

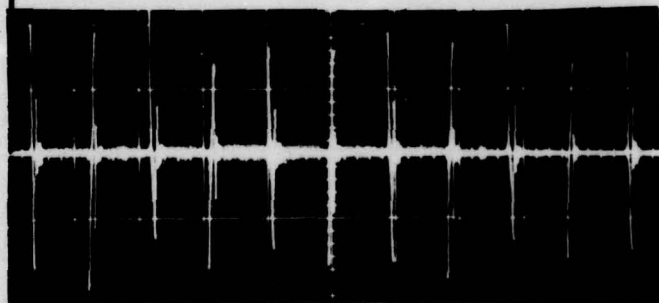
50V / DIV.

500 μSEC / DIV.



20V / DIV.

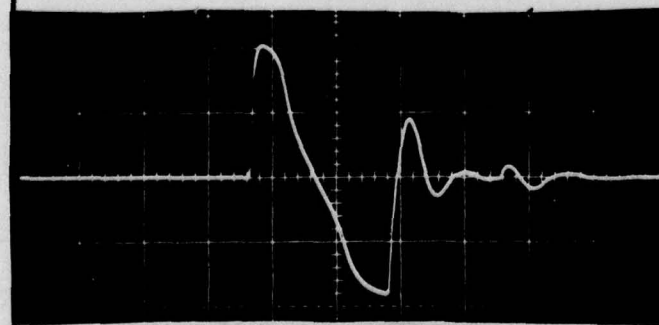
100 μSEC / DIV.



VOLTAGE ACROSS L₂

50V / DIV.

500 μSEC / DIV.



20V / DIV.

100 μSEC / DIV.

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.

0006

PAGE

JOB NO.

DESIGN

DATA

24

TITLE

PREPARED

CORRY

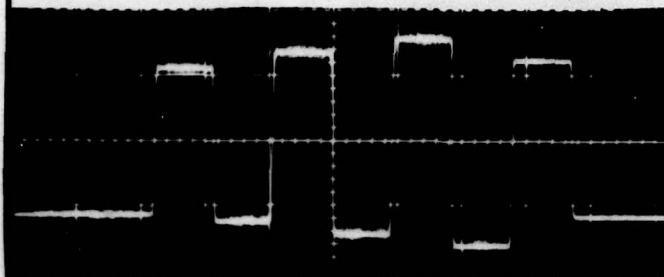
DATE

11/15/74

CHECKED

APPROVED

BOOST CIRCUIT WAVEFORMS



VOLTAGE ACROSS C_2

50V/DIV.

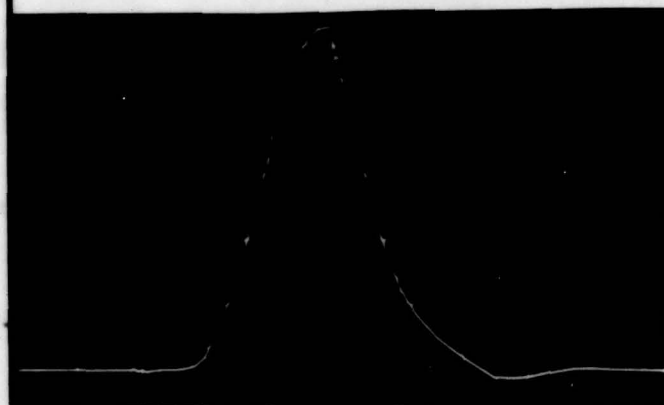
500 μ SEC/DIV



CURRENT THRU C_2

200A/DIV

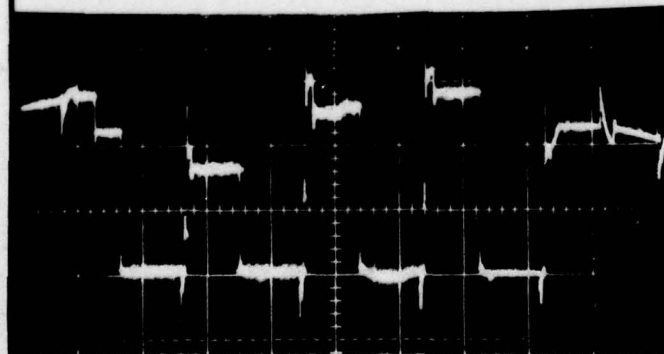
500 μ SEC/DIV.



CURRENT THRU C_2

50A/DIV

10 μ SEC/DIV.



VOLTAGE ACROSS L_{SA}

50V/DIV.

500 μ SEC/DIV.

11KW, PF = 0.8

DISTRIBUTION:

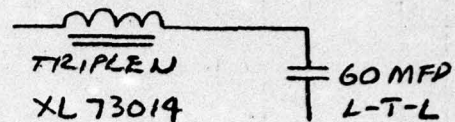
TITLE

PREPARED
CORY 11/15/74

CHECKED

APPROVED

60 HZ OUTPUT FILTER EXPERIMENTS



LINE-TO-NEUTRAL VOLTAGE

NO LOAD

NO LOAD

16 KW, PF=0.8

DISTRIBUTION:

TITLE

PREPARED

CORRY

DATE

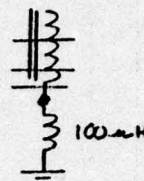
11/15/74

CHECKED

APPROVED

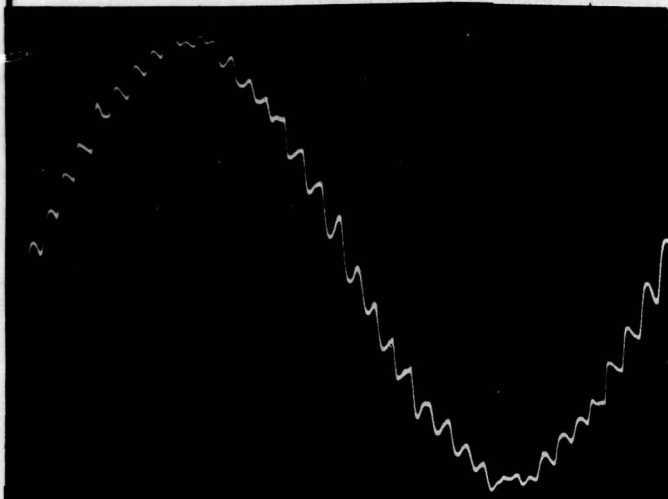
60HZ FILTER EXPERIMENTS

- 100 μ H ADDED IN SERIES WITH STEP TRANSFORMER

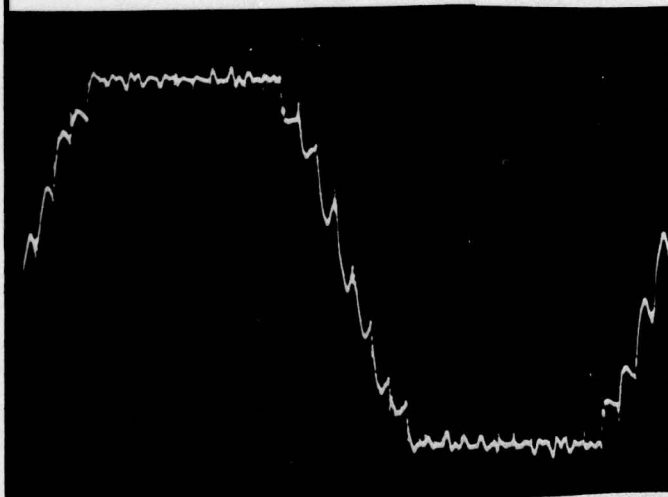


- OUTPUT FILTER 60MFD L-T-L
XL 73014 TRIPLEN

L-T-N VOLTAGE
100V/DIV.



INVERTER BASIC VOLTAGE
100V/DIV.



DISTRIBUTION:

TITLE

PREPARED

CORRY 11/18/74

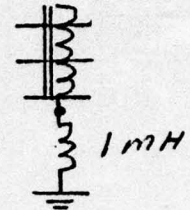
DATE

CHECKED

APPROVED

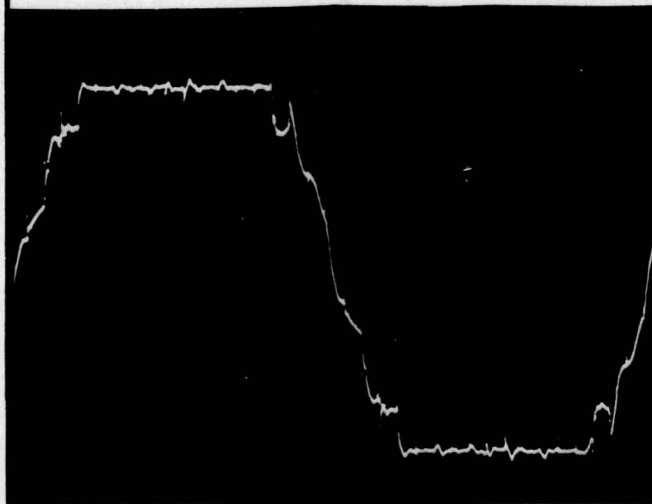
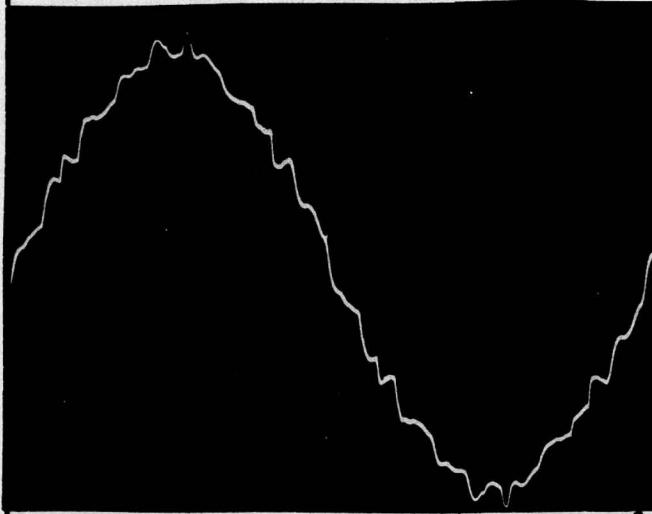
60HZ FILTER EXPERIMENTS

- 1MH ADDED IN SERIES WITH STEP TRANSFORMER



- OUTPUT FILTER 60MFD
L-T-L, XL73014 TRIPLEN

L-T-N VOLTAGE
100V/DIV.



INVERTER BASIC VOLTAGE
100V/DIV.

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.
0006

PAGE

JOB NO.

DESIGN
DATA

PAGE

28

TITLE

PREPARED

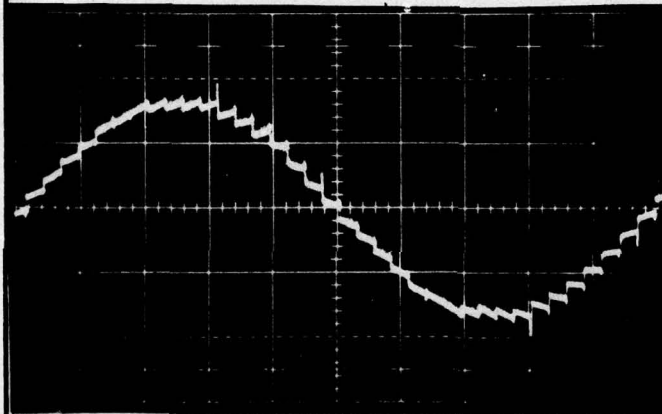
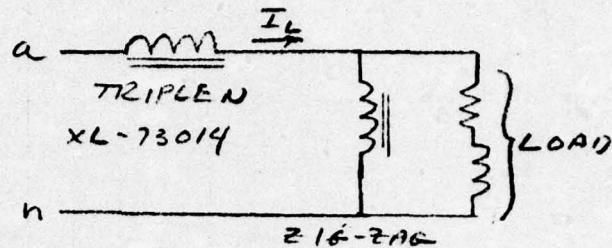
CORY

DATE

11/18/74

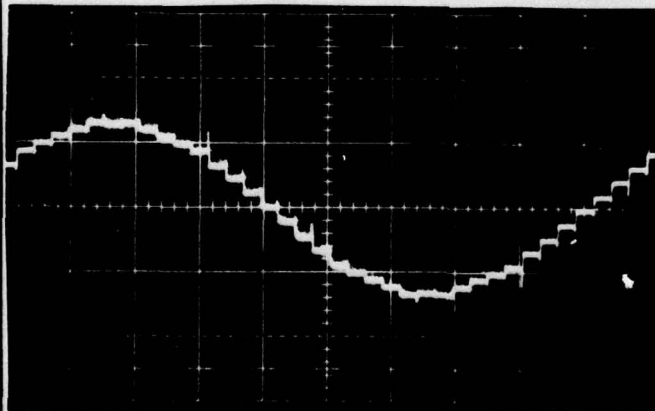
CHECKED

APPROVED

LOAD CURRENT 60HZ, THREE PHASELINE CURRENT

16KW, PF=0.8 LOAD

50A/DIV.



16KW, PF=1.0 LOAD

50A/DIV.

(NOTE PHASE SHIFT).

DISTRIBUTION:

TITLE

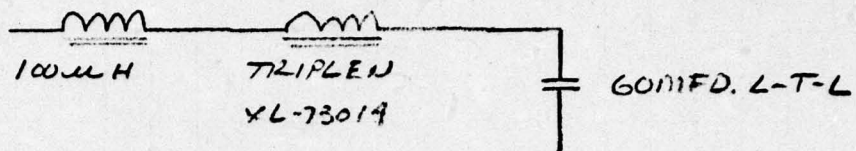
PREPARED
CARRY

DATE
11/18/79

CHECKED

APPROVED

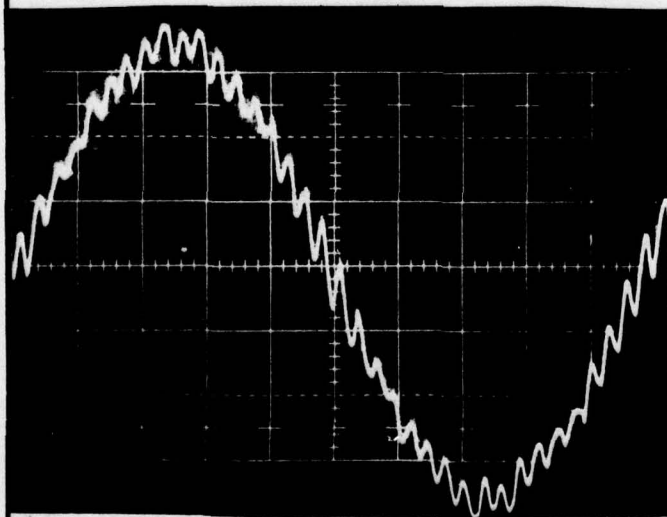
60HZ FILTER EXPERIMENTS



L-T-N VOLTAGE

NO LOAD

THD = 4.6%



16KW, PF=0.8

THD = 7.68%

DISTRIBUTION:

AD-A035 045

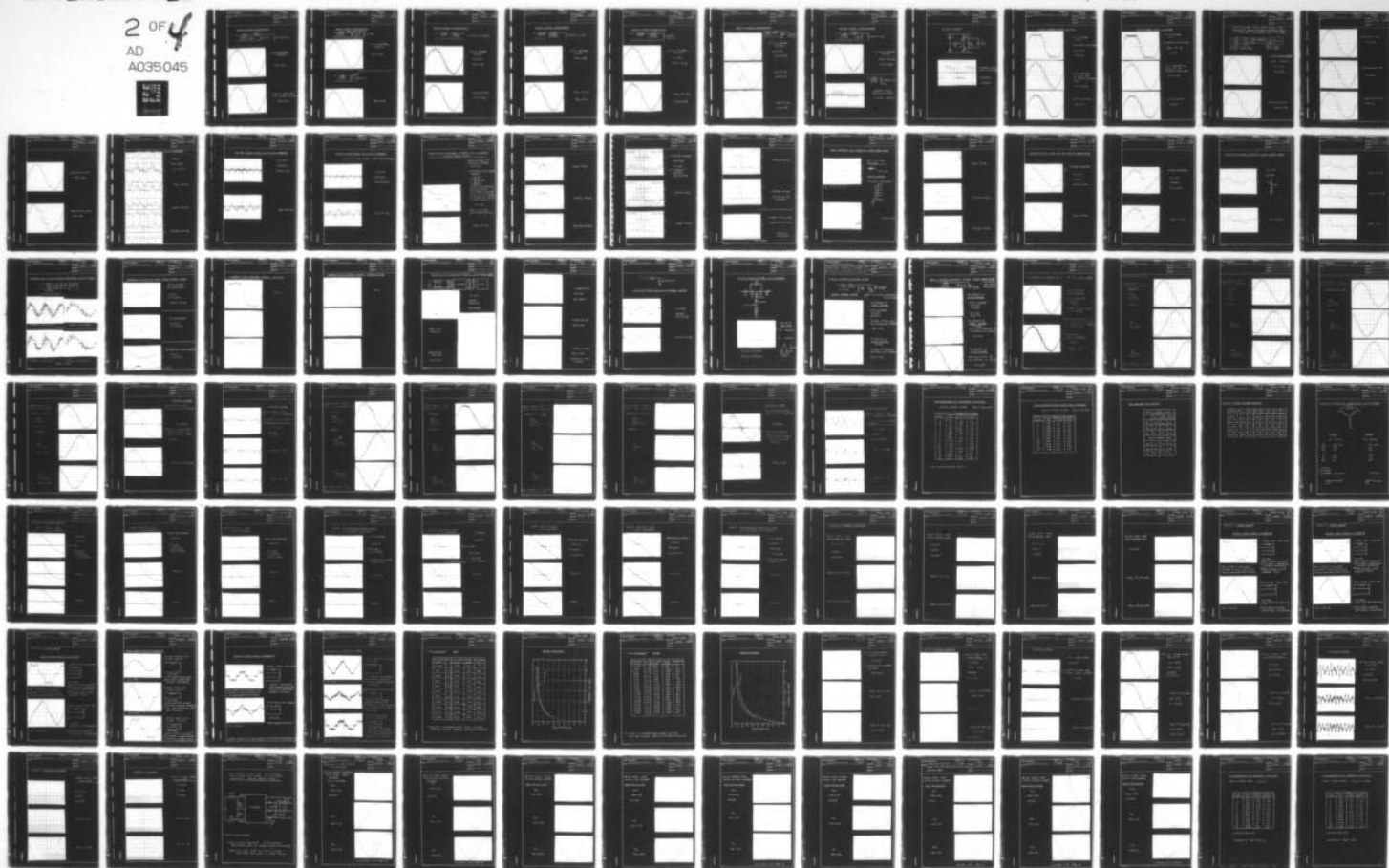
GENERAL MOTORS CORP GOLETA CALIF DELCO ELECTRONICS DIV F/6 9/5
FREQUENCY CONVERTER PORTABLE, ALTERNATING CURRENT MULTIFREQUENC--ETC(U)
JAN 75 T CORRY DAAK02-72-C-0210

UNCLASSIFIED

R75-3

NL

2 OF 4
AD
A035045



DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.
ITEM NO.
0006

PAGE JOB NO.
DESIGN
DATA

30

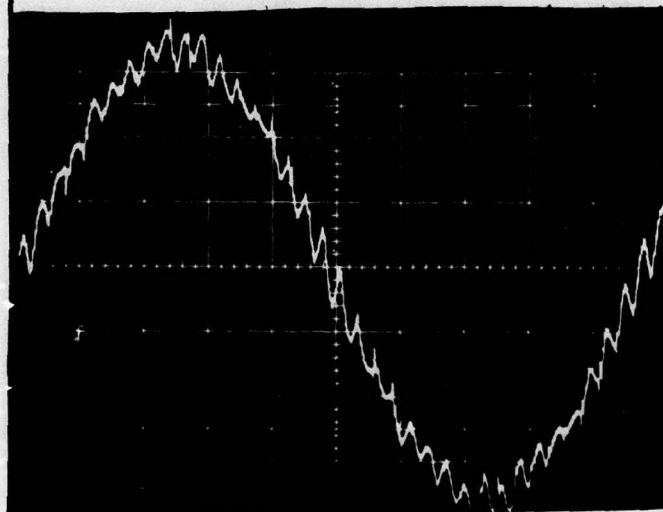
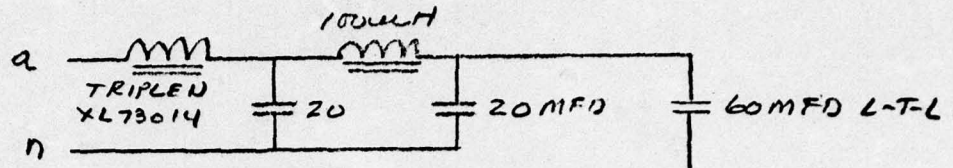
TITLE

PREPARED CARRY 11/18/79

CHECKED

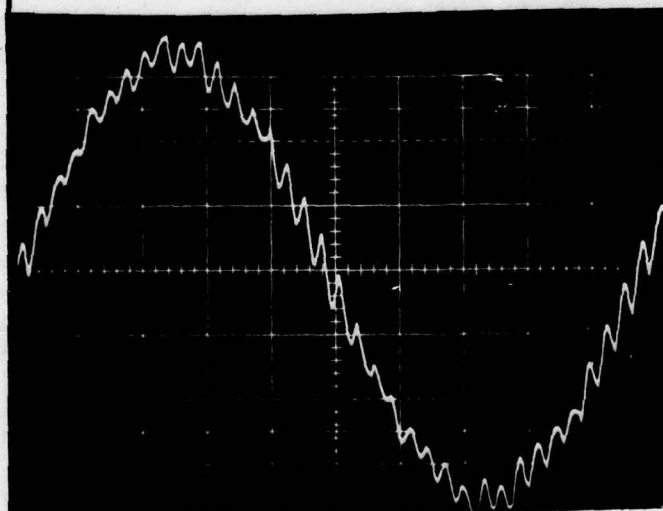
APPROVED

60HZ FILTER EXPERIMENTS



L-T-N VOLTAGE
100V/DIV.

THD = 6.9%



SAME AS ABOVE BUT
WITH NEUTRAL REMOVED.

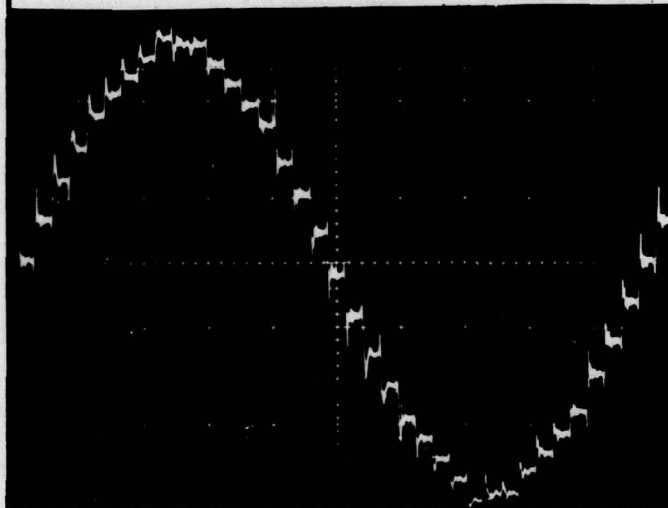
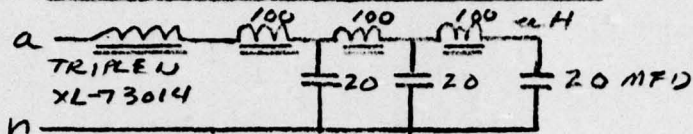
THD = 6.7%

DISTRIBUTION:

TITLE

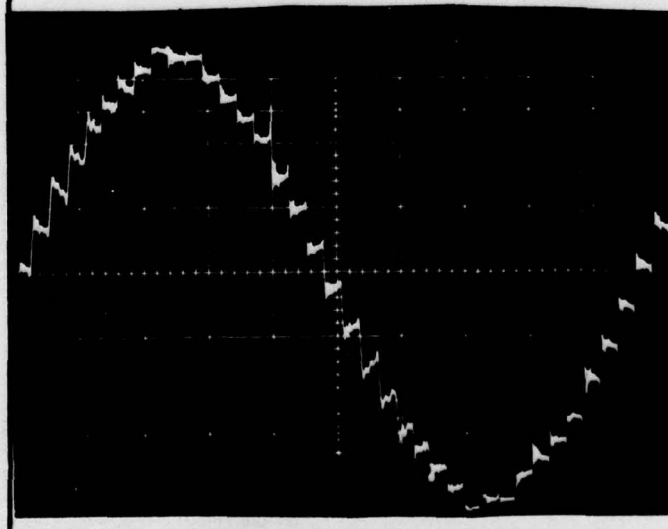
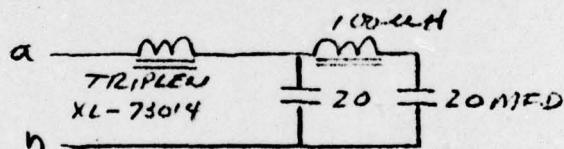
PREPARED CORRY DATE 11/16/79
CHECKED
APPROVED

60HZ FILTER EXPERIMENTS



L-T-N VOLTAGE
100V/DIV.

THD = 6.5%



THD = 7.3%

DISTRIBUTION:

TITLE

PREPARED

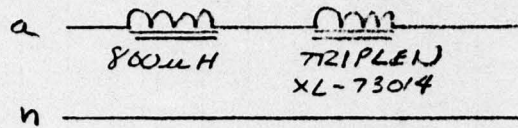
CORY

DATE

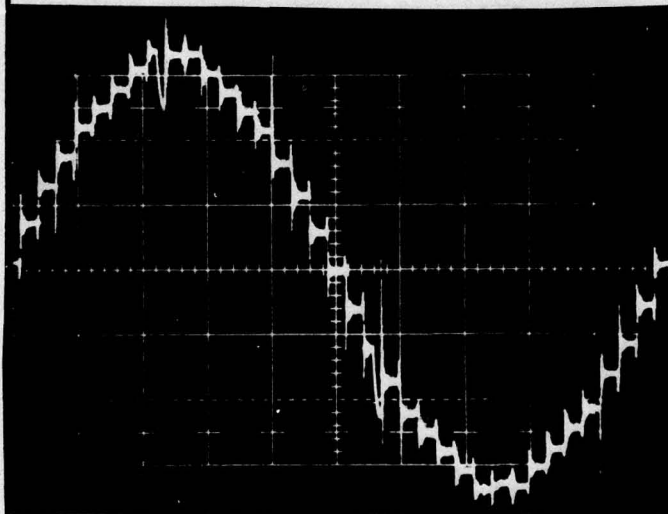
11/16/74

CHECKED

APPROVED

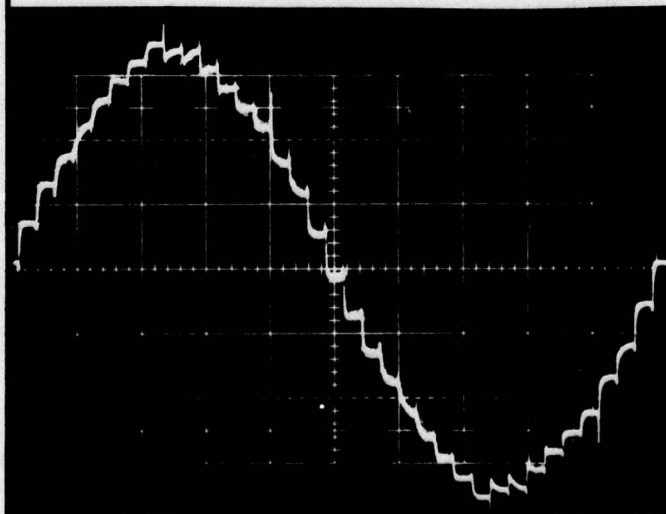
60 HZ FILTER EXPERIMENTS

NO OUTPUT CAPACITORS

L-T-N VOLTAGE
100V/DIV.

NO LOAD

THD = 7.6%



16 KW, PF = 0.8

THD = 5.8%

DISTRIBUTION:

TITLE

PREPARED

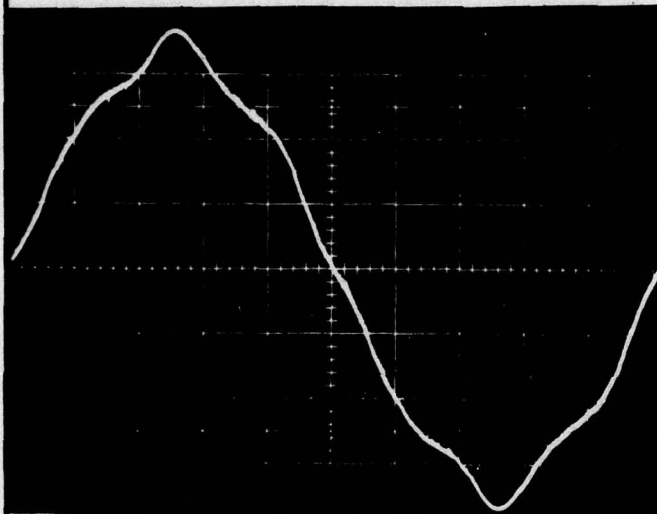
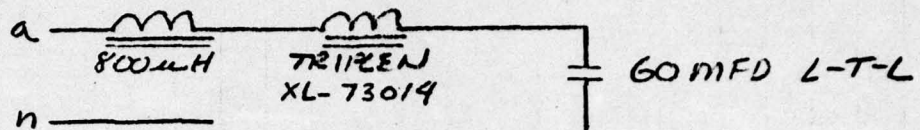
CORY

DATE

11/18/79

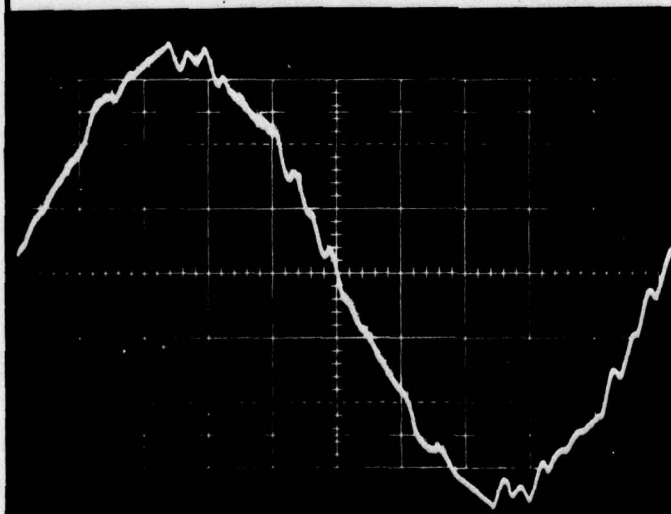
CHECKED

APPROVED

60 HZ FILTER EXPERIMENTS

L-T-N VOLTAGE
100V/DIV.

THD = 5.3%



11KW, PF = 0.8

THD = 4.7%

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.
ITEM NO.
0006PAGE JOB NO.
DESIGN
DATAPAGE
34

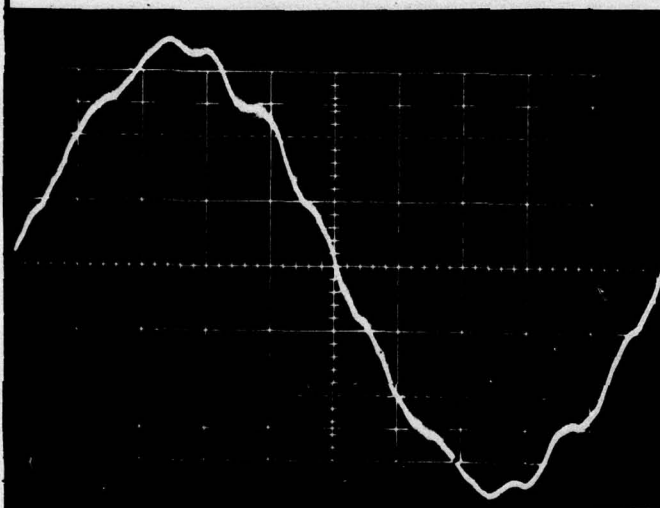
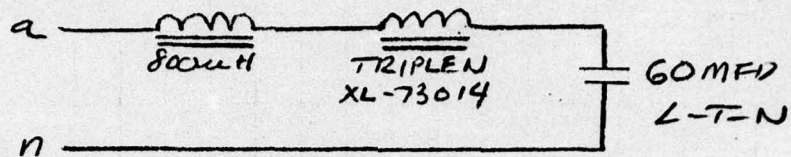
TITLE

PREPARED
CORRY 11/18/74

DATE

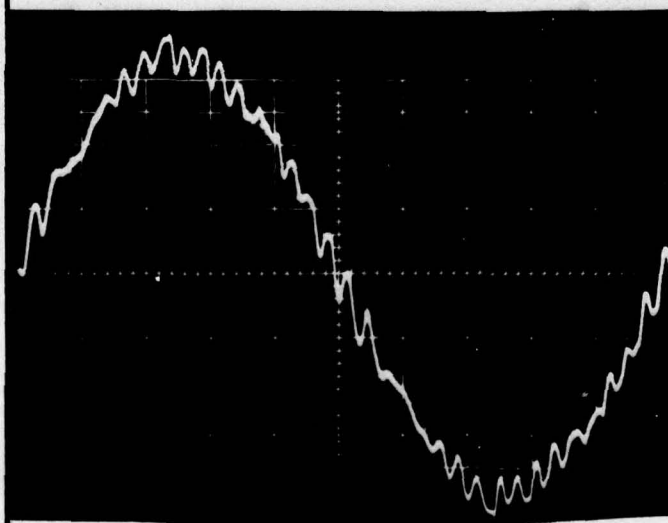
CHECKED

APPROVED

60 HZ. FILTER EXPERIMENTSL-T-N VOLTAGE
100V/DIV.

NO LOAD

THD = 4.3%



11KW, PF = 0.8

THD = 6.7%

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.
0006

PAGE

JOB NO.

DESIGN
DATA

PAGE

35

TITLE

PREPARED

CORR-1

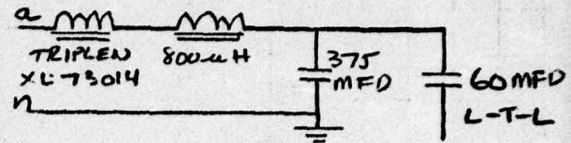
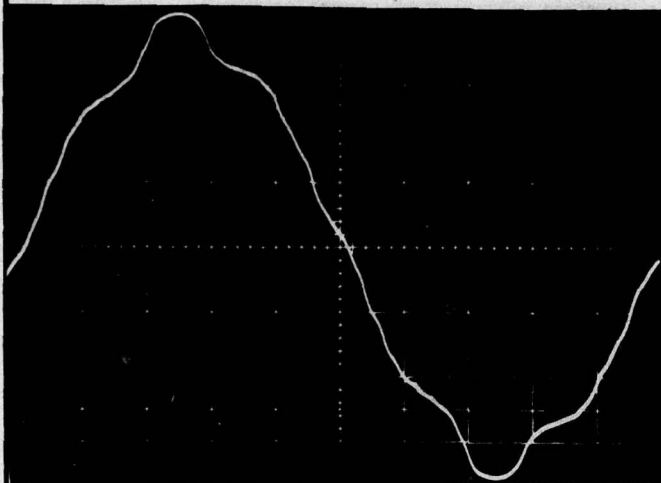
DATE

11/18/74

CHECKED

APPROVED

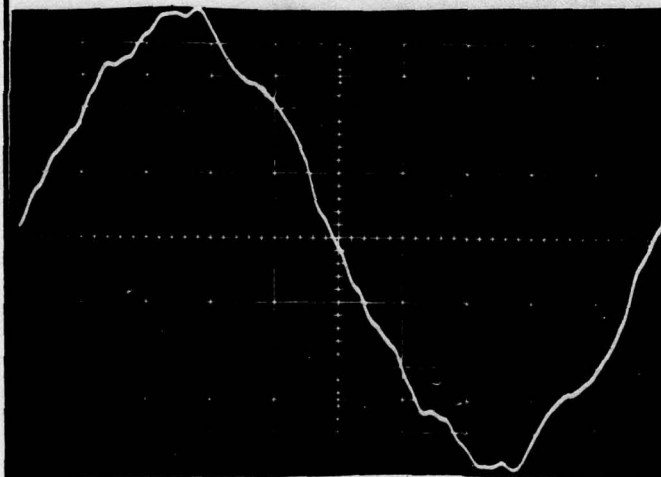
60 HZ FILTER EXPERIMENTS



L-T-N VOLTAGE
100V/DIV.

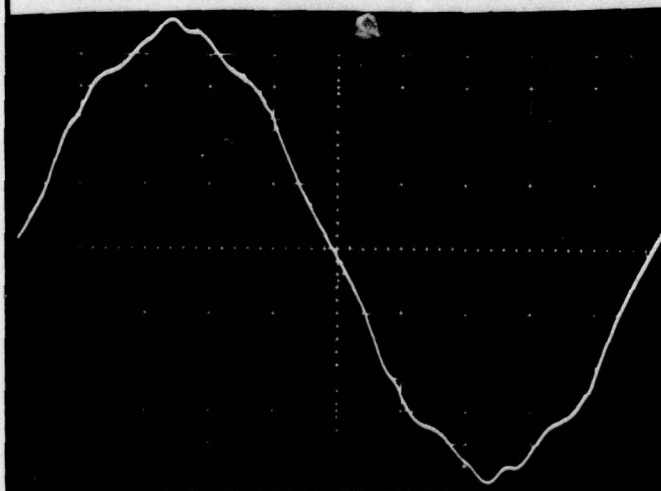
NO LOAD

THD = 6.6%



11KW, PF=1.0

THD = 5.5%



11KW, PF=0.8

THD = 3.9%

DISTRIBUTION:

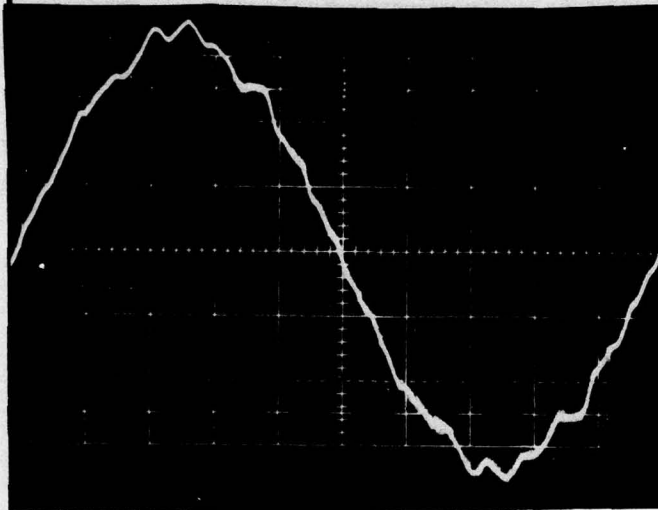
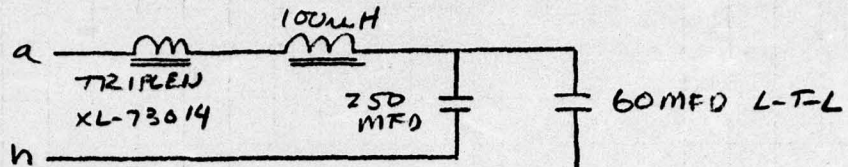
TITLE

PREPARED
CORRY 11/18/74

CHECKED

APPROVED

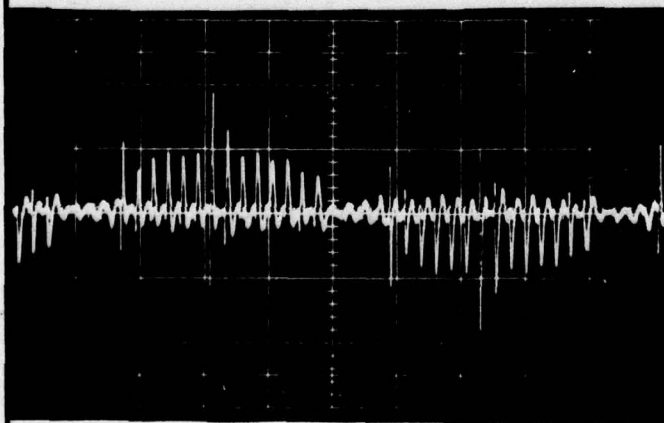
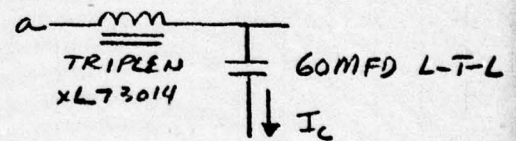
60 HZ FILTER EXPERIMENTS.



L-T-N VOLTAGE
100V/DIV

6KW, PF=0.8

THD=3.8%



CURRENT THRU
60 MFD CAPACITOR

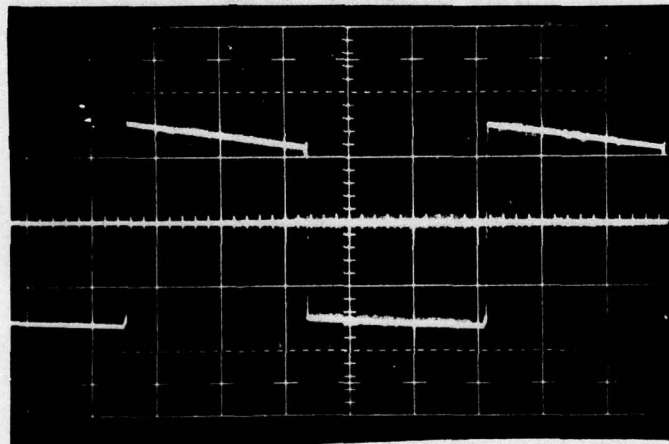
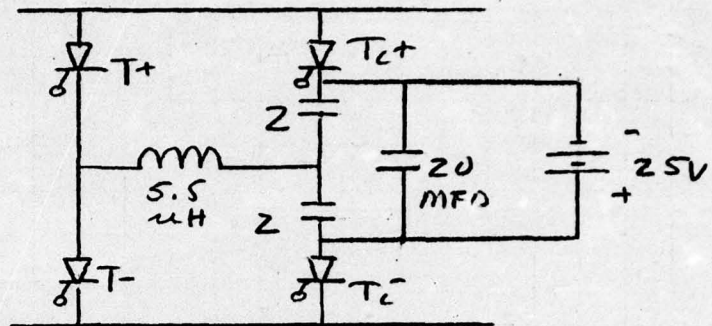
10A/DIV. 2MS/DIV.

DISTRIBUTION:

TITLE

PREPARED
CORRY 11/18/79
CHECKED
APPROVED

T_c^+, T_c^- CIRCUIT



VOLTAGE ACROSS
20 MFD. CAPACITOR

100V/DIV.

1MS/DIV.

DISTRIBUTION:

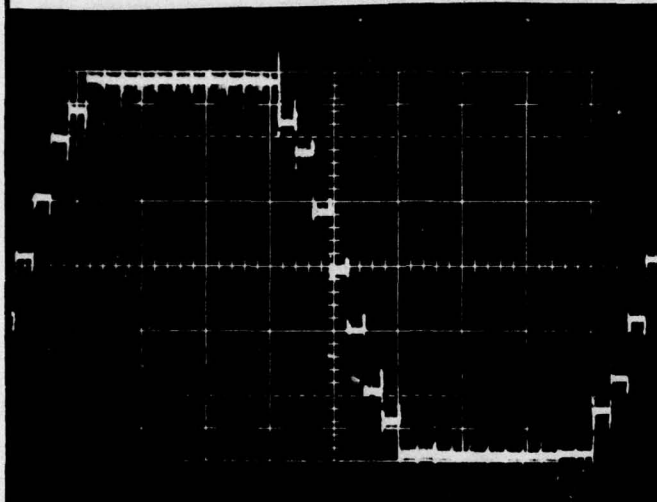
TITLE

PREPARED
CORRY 11/19/74

CHECKED

APPROVED

60HZ THREE PHASE VOLTAGES

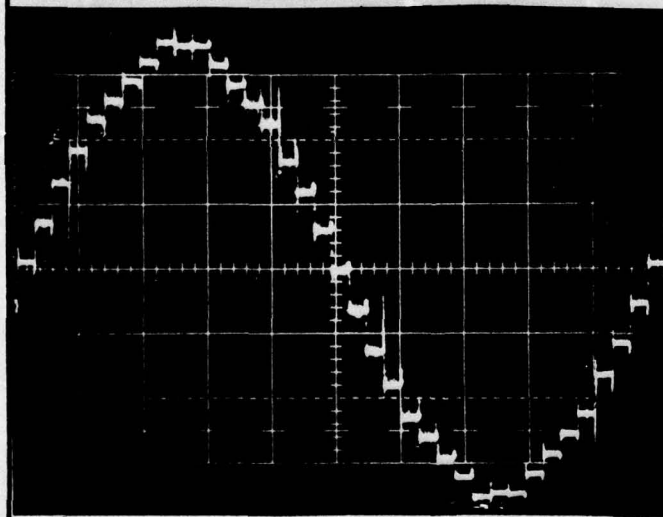


L-T-N VOLTAGE
 V_{a-n}

NO OUTPUT CAPACITANCE

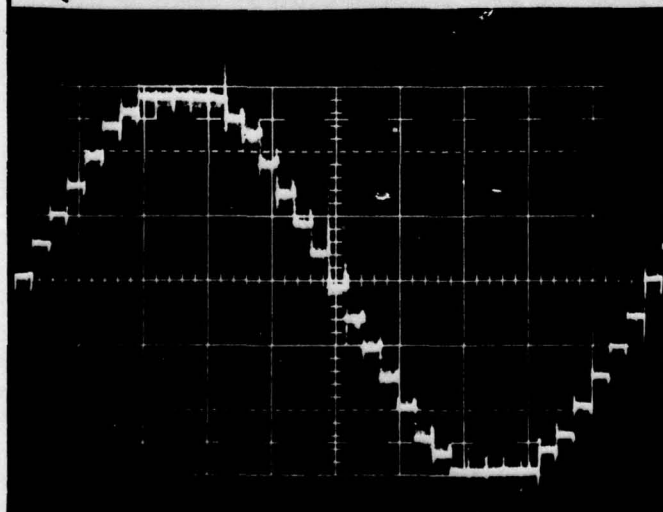
NO LOAD

50V / DIV.



L-T-N VOLTAGE
ON LOAD SIDE
OF TRIPLEN ATTENU-
ATOR

THD = 5.65%



L-T-L VOLTAGE

100V / DIV.

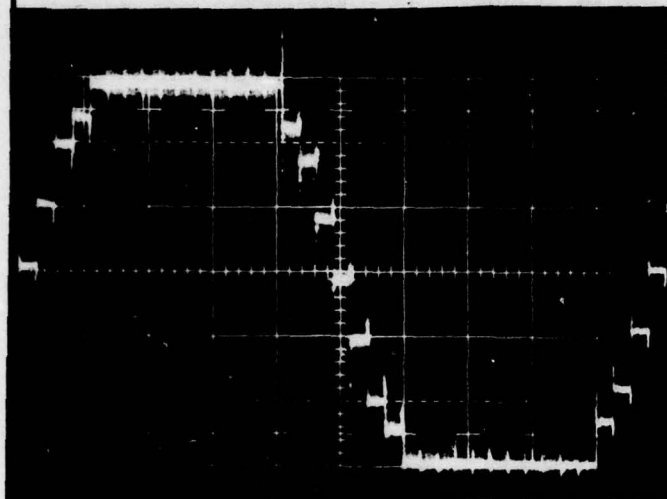
DISTRIBUTION:

TITLE

PREPARED CORRY 11/19/74

CHECKED

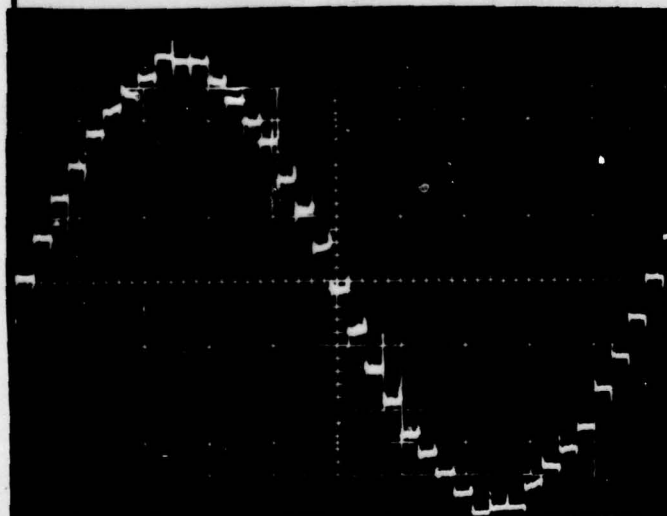
APPROVED

60 HZ THREE PHASE VOLTAGESL-T-N VOLTAGE
 V_{a-n}

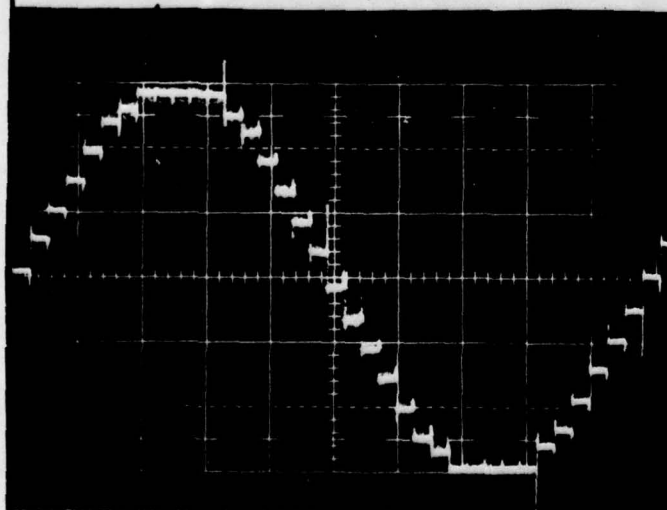
NO OUTPUT CAPACITANCE

16KW, PF = 0.8

50V/DIV.

L-T-L VOLTAGE ON
LOAD SIDE OF
TRIPLEN ATTENUATOR

THD = 7%



L-T-L VOLTAGE

100V/DIV.

DISTRIBUTION:

TITLE

PREPARED

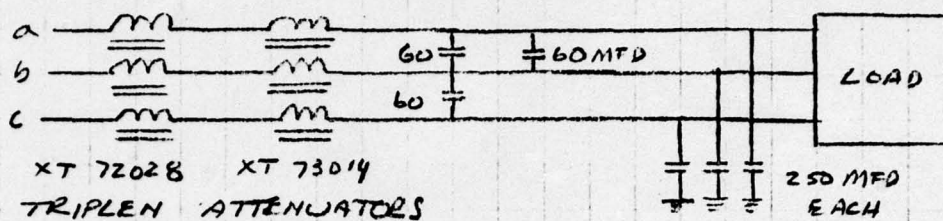
CORRY 11/19/74

DATE

CHECKED

APPROVED

OUTPUT VOLTAGES FOR 60HZ, THREE PHASE
OPERATION, POWER FACTOR CORRECTED MODE.
(AUXILIARY COMMUTATION STEPS NOT USED)

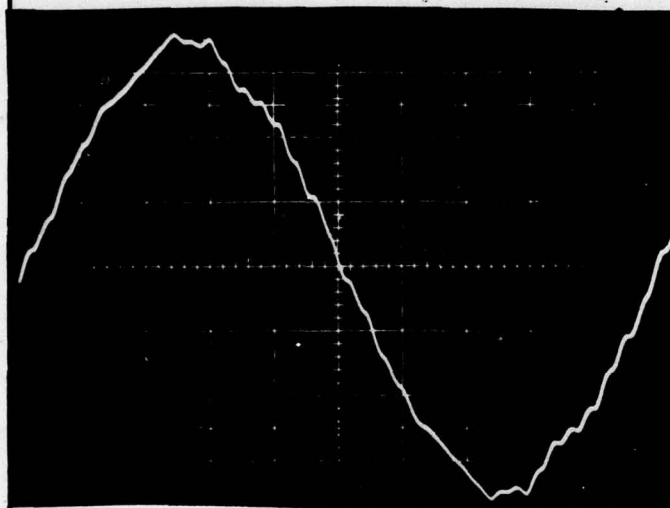


L-T-N OUTPUT VOLTAGES

V_{an} 120Vrms

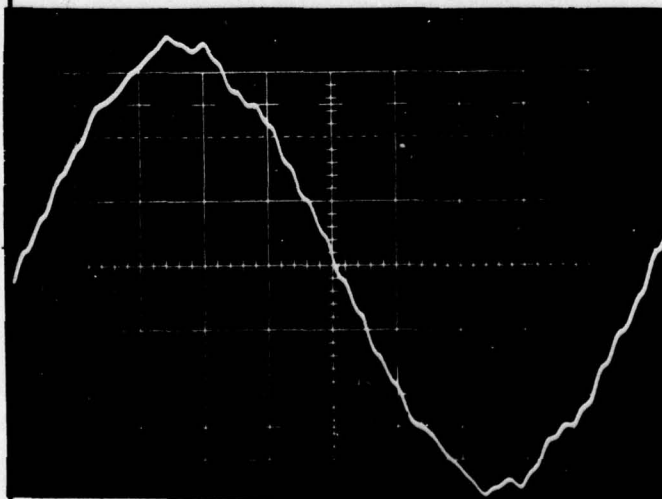
NO LOAD

THD = 3.5%



2.2kW, 0.8 PF LOAD

THD = 3.14%



DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.

0006

PAGE

JOB NO.

DESIGN

DATA

PAGE

41

TITLE

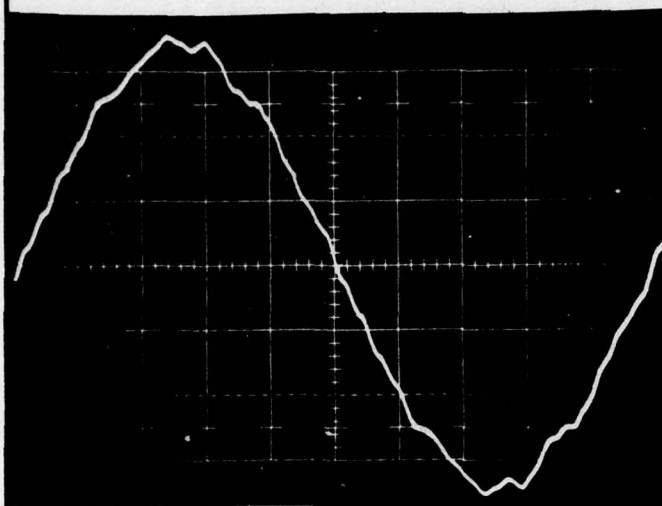
PREPARED

CHECKED

APPROVED

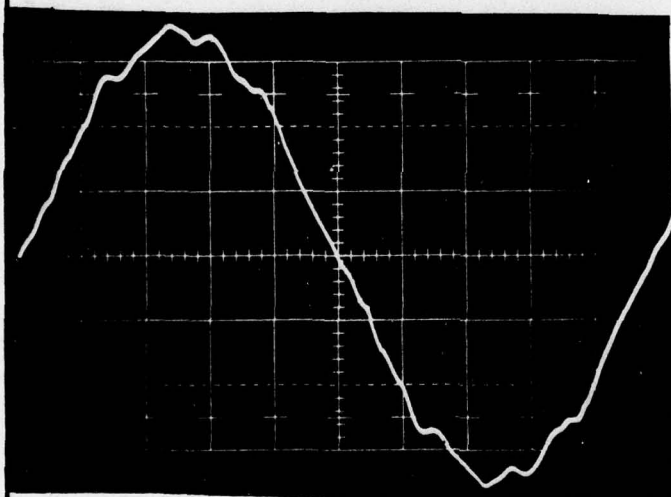
DATE

CORRY 11/19/79



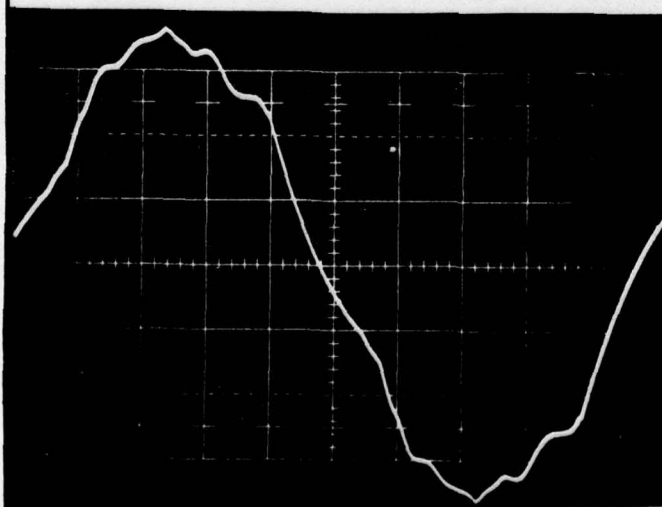
4.4KW, 0.8 PF LOAD

THD = 3.2%



6.6KW, 0.8 PF LOAD

THD = 3.8%



8.8KW, 0.8 PF LOAD

THD = 7%

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.
0006

PAGE

JOB NO.

DESIGN
DATA

PAGE

42

TITLE

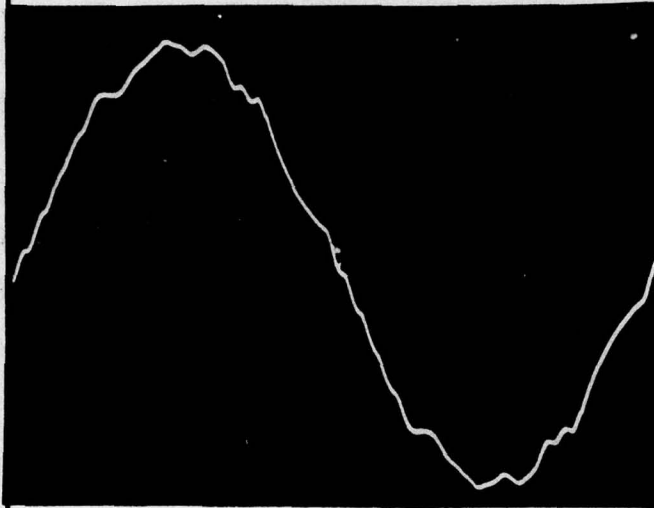
PREPARED

CORRY 11/19/74

DATE

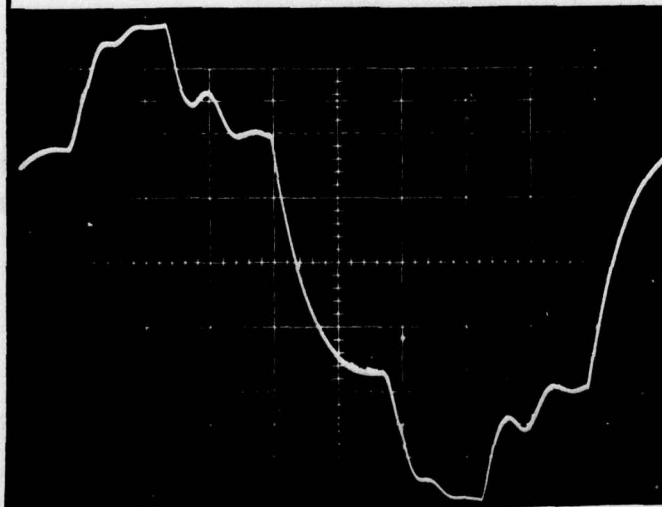
CHECKED

APPROVED



16KW, PF=1.0 LOAD

THD= 4.3%



16KW, PF=0.8 LOAD

THD= 17%

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.

0006

PAGE

JOB NO.

DESIGN
DATA

PAGE

43

TITLE

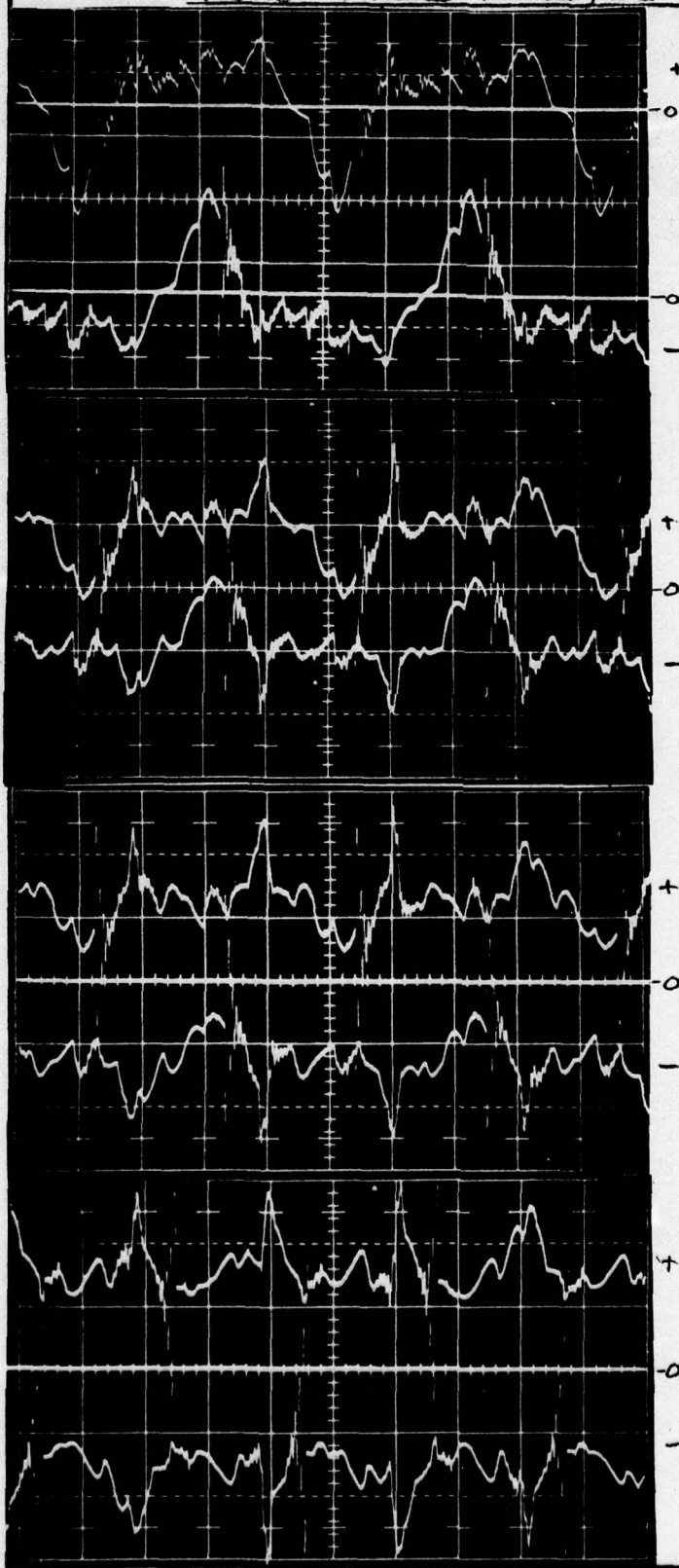
PREPARED

DATE

CORY 11/19/74

CHECKED

APPROVED

400 HZ THREE PHASE, DC INPUT CURRENTS

50A/DIV.

200 μ S/DIV.

NO LOAD

11KW, PF=0.8

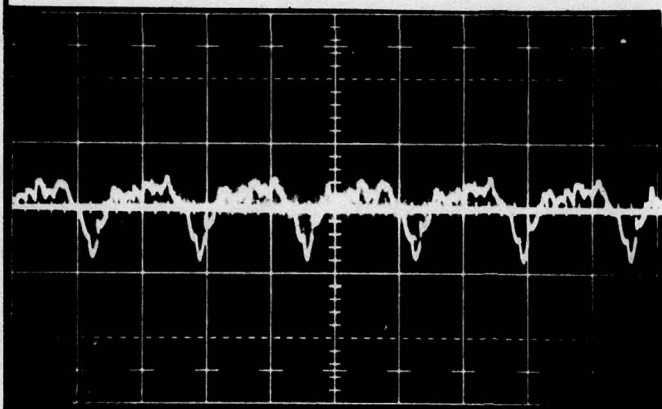
16KW, PF=0.8

20.6KW, PF=0.8

DISTRIBUTION:

DELCO ELECTRONICS GENERAL MOTORS CORPORATION	REPORT NO. ITEM NO. 0006	PAGE JOB NO. DESIGN DATA	PAGE 44
	TITLE PREPARED CORRY CHECKED APPROVED DATE 11/19/74		

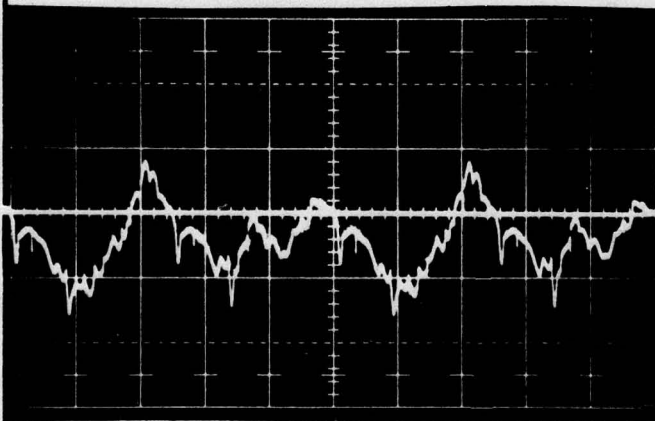
400 HZ SINGLE PHASE, DC INPUT CURRENTS



NO LOAD

100 A / DIV.

500 μ sec / DIV.



11 KW, PF = 0.8

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.

0006

PAGE

JOB NO.

DESIGN
DATA

PAGE

45

TITLE

PREPARED

CORRY

DATE

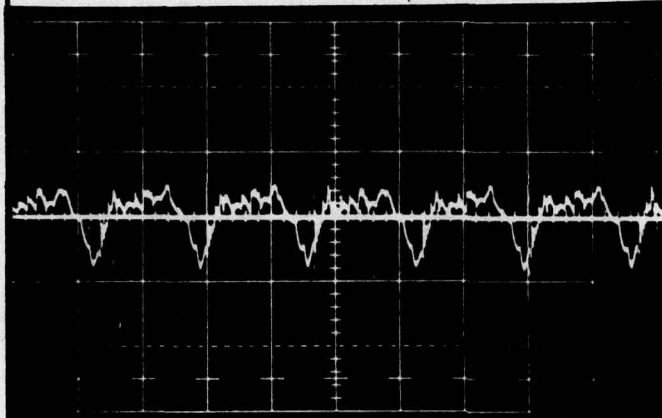
11/19/74

CHECKED

APPROVED

400HZ SINGLE PHASE, DC INPUT CURRENTS

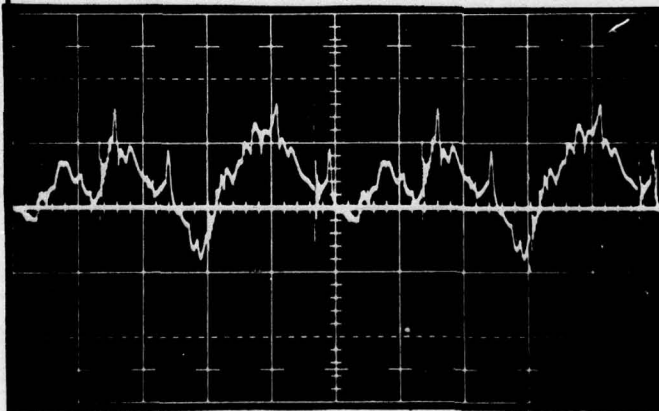
(1 MFD) CAPACITOR ACROSS STEP-TRANSFORMER)



NO LOAD

100 A / DIV.

500 μ SEC / DIV.



11 KW, PF = 0.8

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.

0006

PAGE

JOB NO.

DESIGN

DATA

46

TITLE

PREPARED

CORRY

DATE

11/20/79

CHECKED

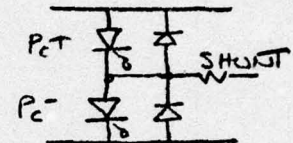
APPROVED

POWER CENTER THYRISTOR VOLTAGES AND CURRENTS.
400HZ, THREE PHASE

POWER CENTER P_c^-
THYRISTOR VOLTAGE

200V/DIV.

THYRISTOR & DIODE CURRENT
50A/DIV.

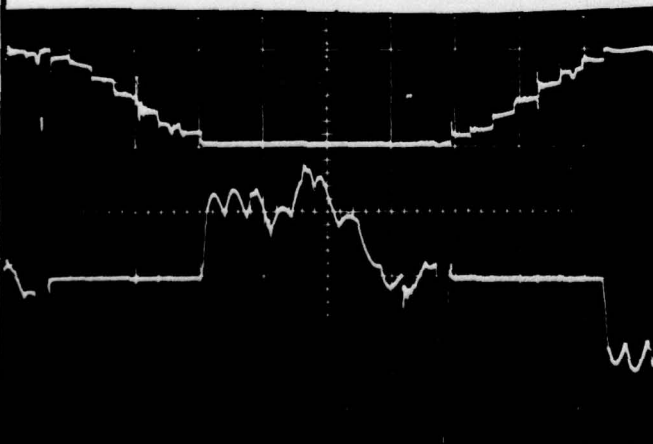
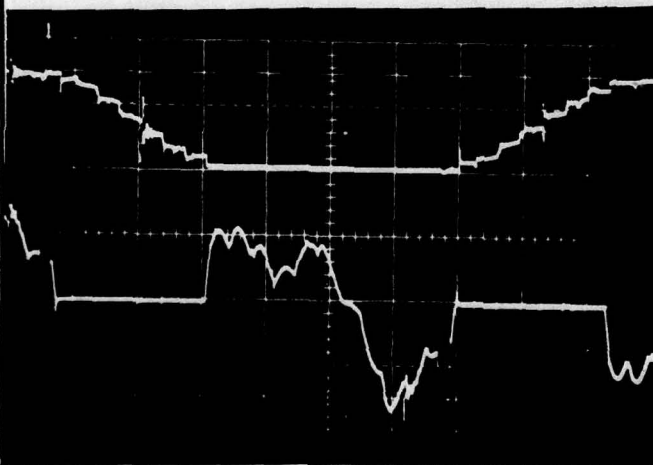


(BOOST COMMUTATION)
VOLTAGE = 72VDC
CURRENT = 6AMPS DC
FOR ALL V&I PICTURES
JAPANESE C.T. COMMU-
TATION XFAIR IN.

NO LOAD

(NOTE: BY PASS DIODE
PEAK CURRENT = 210AMPS)

11KW, PF = 0.8



DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.

0006

PAGE

JOB NO.

DESIGN

DATA

PAGE

47

TITLE

PREPARED

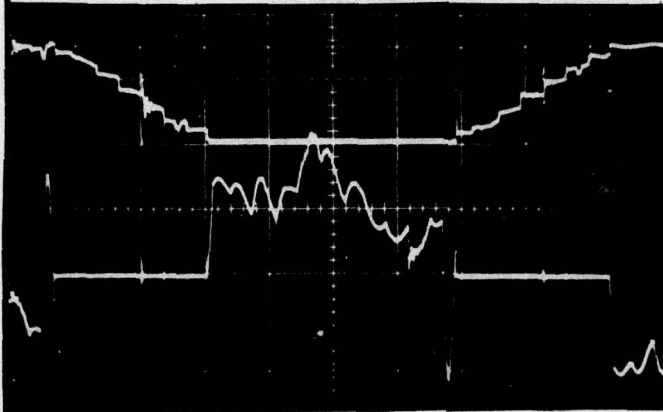
CORRY

DATE

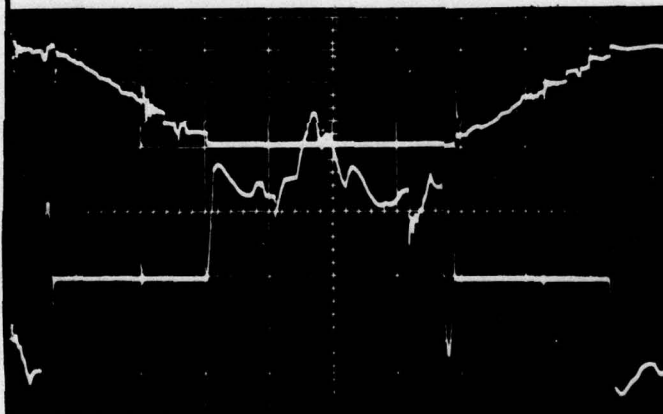
11/24/74

CHECKED

APPROVED



16KW, PF=0.8



20.6KW, PF=0.8



24.8KW, PF=0.8

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.

0006

PAGE

JOB NO.

DESIGN

DATA

PAGE

48

TITLE

PREPARED

CORRY

11/20/74

DATE

CHECKED

APPROVED



T- THYRISTOR VOLTAGE

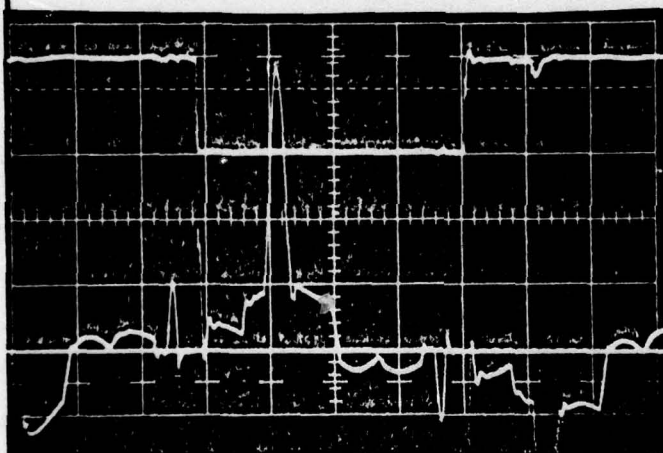
200V / DIV.

NO LOAD

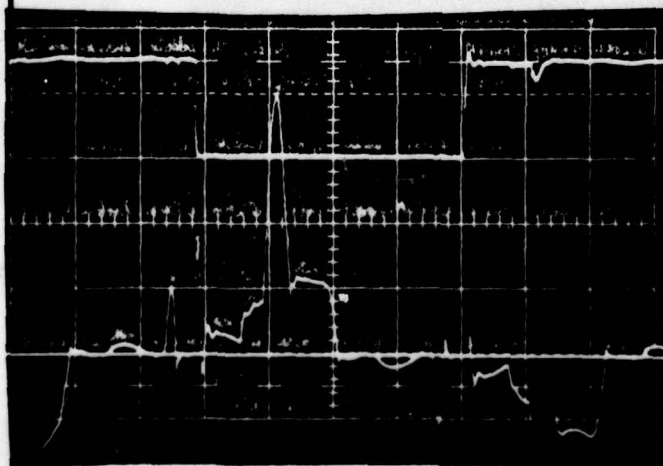
T- CURRENT

50A / DIV.

100μSEC / DIV.



11KW, PF=0.8



16KW, PF=0.8

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.

0006

PAGE

JOB NO.

DESIGN

DATA

PAGE

49

TITLE

PREPARED

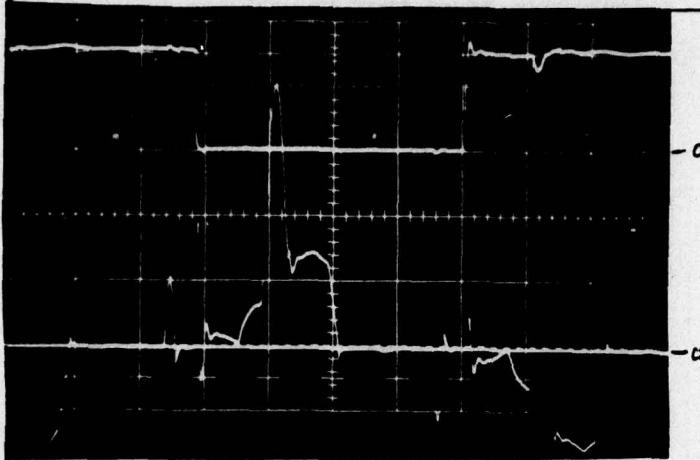
CORY

DATE

11/20/74

CHECKED

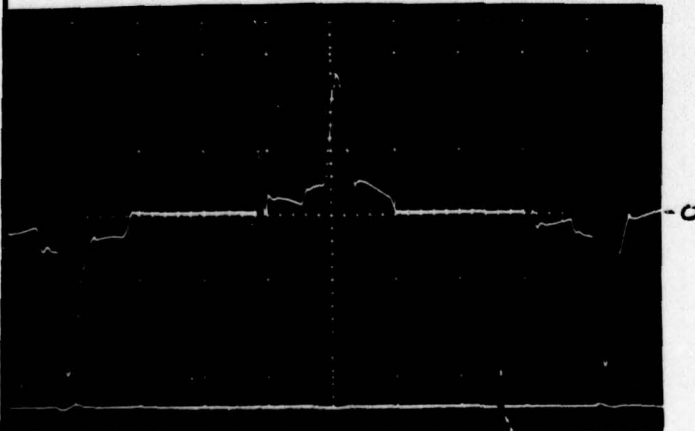
APPROVED



20.6 KW, PF=0.8



24.8 KW, PF=0.8

(92 AMPS DC INTO
INVERTER)

SINGLE PHASE LOAD

5 KW, PF=0.8 L-T-N

100A/DIV.

100μSEC/DIV.

T_c TRIGGER

DISTRIBUTION:

TITLE

PREPARED

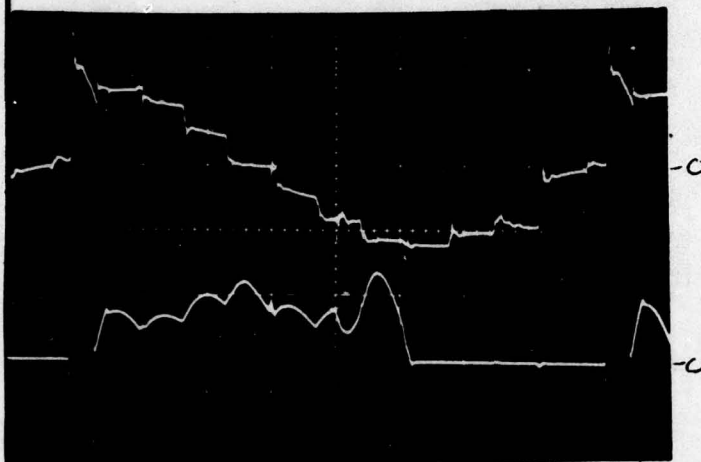
CORRY 11/20/79

DATE

CHECKED

APPROVED

STEP VOLTAGES AND CURRENTS - 400HZ, THREE PHASE



PC 3 2 1 0 1 2 3

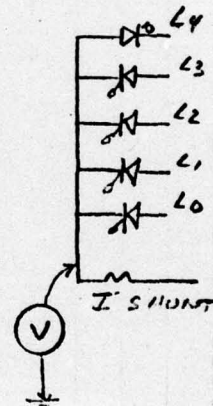
LEFT SIDE STEP VOLTAGE

100V/DIV.

NO LOAD

STEP CURRENT

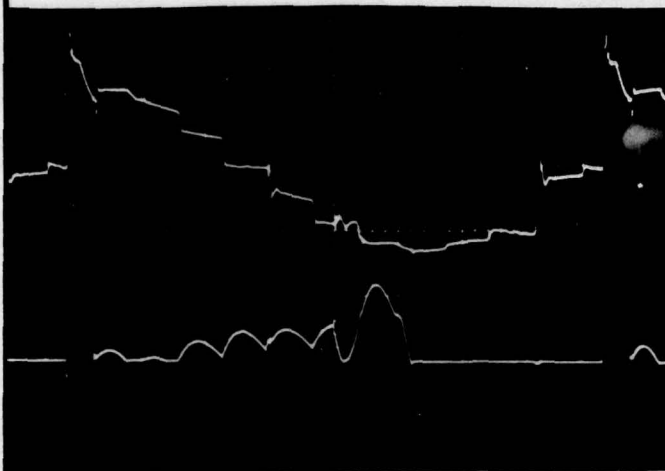
100A/DIV. 100μSEC/DIV.



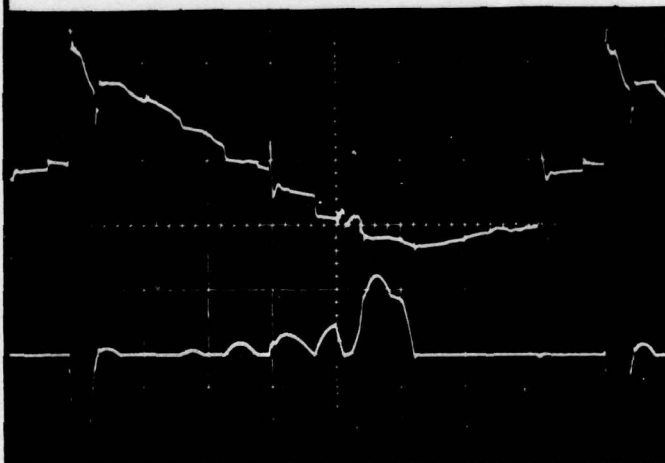
11KW, PF=0.8

DISTRIBUTION:

DELCO ELECTRONICS GENERAL MOTORS CORPORATION	REPORT NO. ITEM NO. 0006	PAGE	JOB NO. DESIGN DATA	PAGE 51
	TITLE		PREPARED CORY 11/20/74	DATE
		CHECKED		
		APPROVED		



16KW, PF=0.8



20.6 KW, PF=0.8

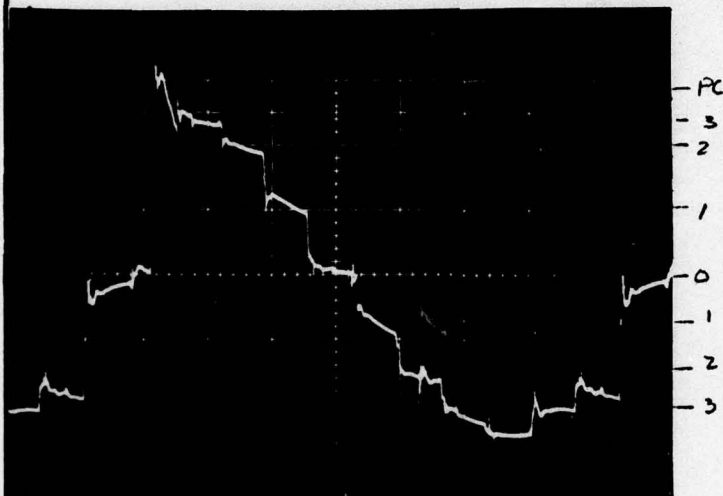


24.8 KW, PF=0.8

DISTRIBUTION:

DELCO ELECTRONICS GENERAL MOTORS CORPORATION	REPORT NO. ITEM NO. 0006	PAGE	JOB NO. DESIGN DATA	PAGE 52
	TITLE		PREPARED CORY 11/20/79	DATE
		CHECKED		
		APPROVED		

AUTOTRANSFORMER STEP VOLTAGES 400HZ, THREE PHASE

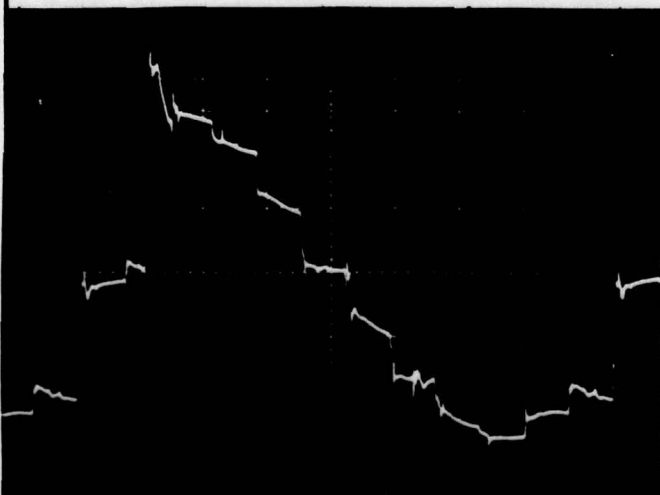


Y STEP FUNCTION

NO LOAD

50V/DIV.

100μSEC/DIV.



11KW, PF=0.8

DISTRIBUTION:

TITLE

PREPARED

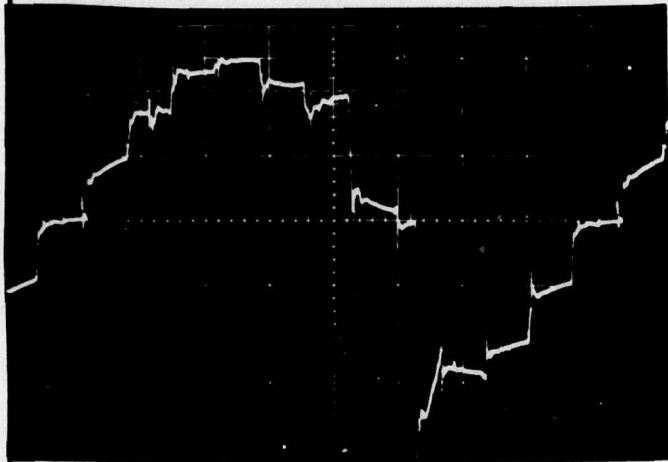
CORRY

DATE

11/20/79

CHECKED

APPROVED

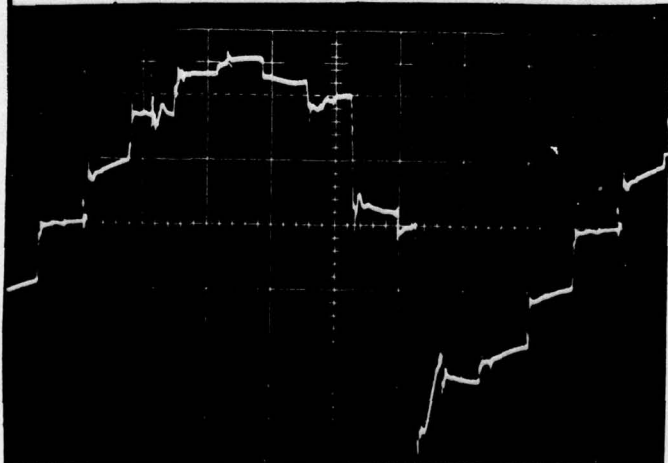


X STEP FUNCTION

NO LOAD

50V/DIV.

100μSEC/DIV.

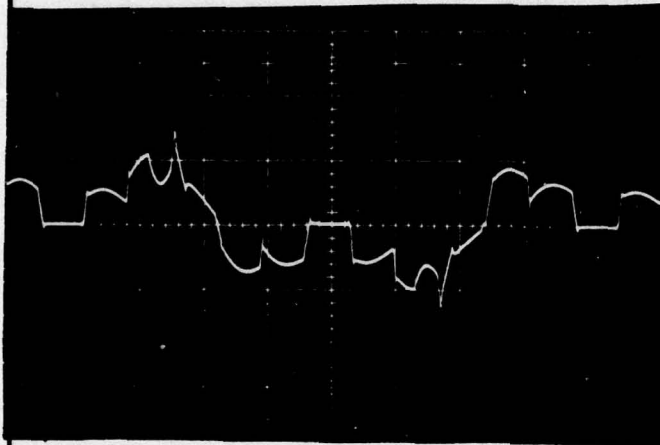


11KW, PF=0.8

DISTRIBUTION:

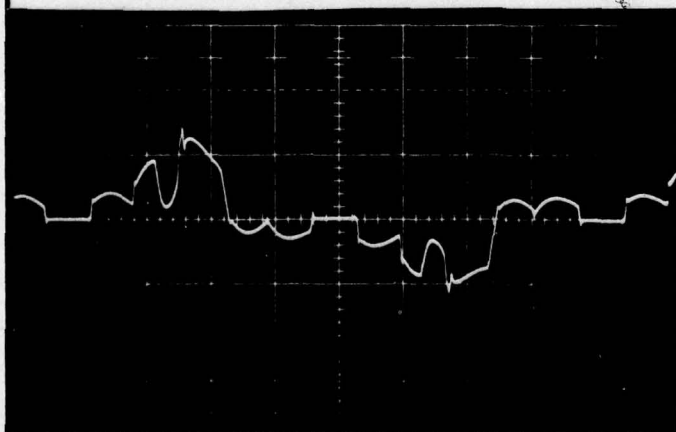
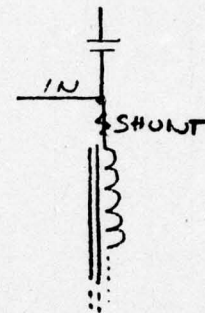
DELCO ELECTRONICS GENERAL MOTORS CORPORATION	REPORT NO. ITEM NO. 0006	PAGE JOB NO. DESIGN DATA	PAGE 54
	TITLE		
PREPARED CORRY		DATE 11/20/74	
CHECKED		APPROVED	

STEP TRANSFORMER CURRENT 400HZ, THREE PHASE



NO LOAD

50A / DIV.



11KW, PF=0.8

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.

0006

PAGE

JOB NO.

DESIGN

DATA

PAGE

55

TITLE

PREPARED

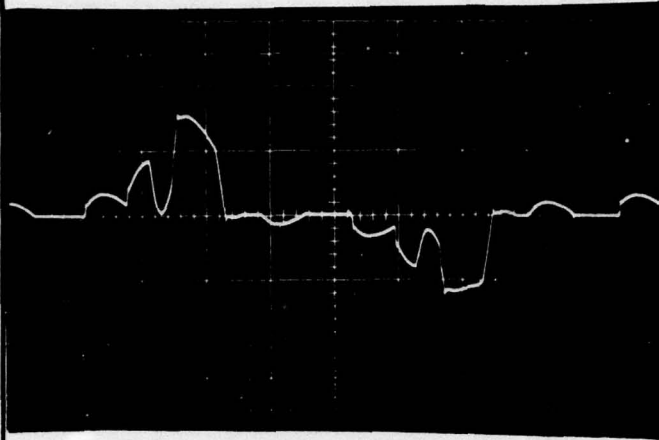
CORRY

DATE

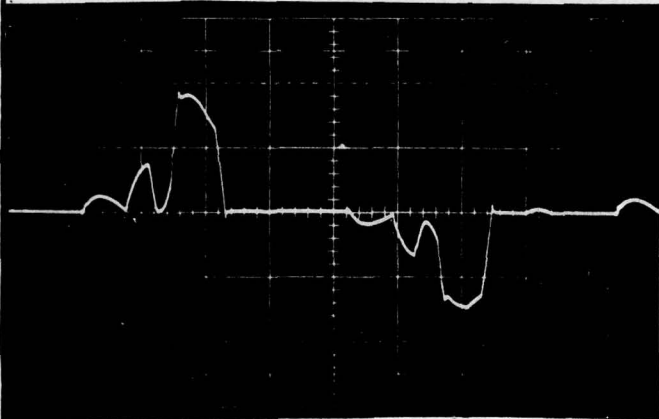
11/20/79

CHECKED

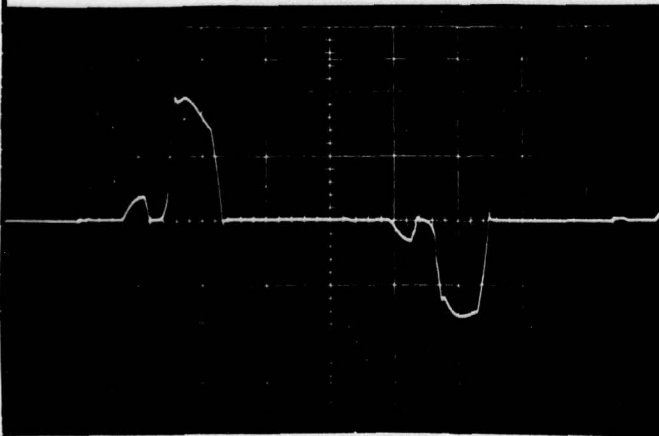
APPROVED



16KW, PF=0.8

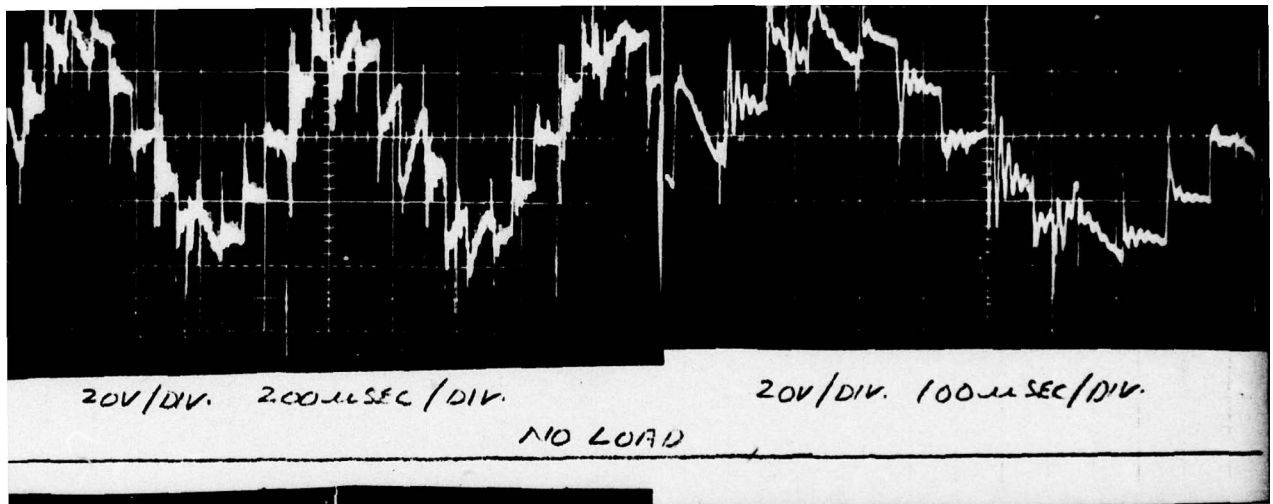


20.6 KW, PF=0.8



24.8, PF=0.8

DISTRIBUTION:



DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.
ITEM NO.
0006

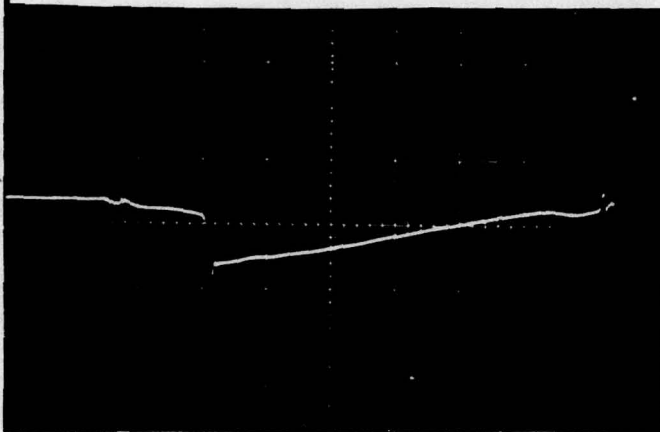
PAGE JOB NO.
DESIGN
DATA

PAGE
57

TITLE

PREPARED
CORY
DATE
11/21/79
CHECKED
APPROVED

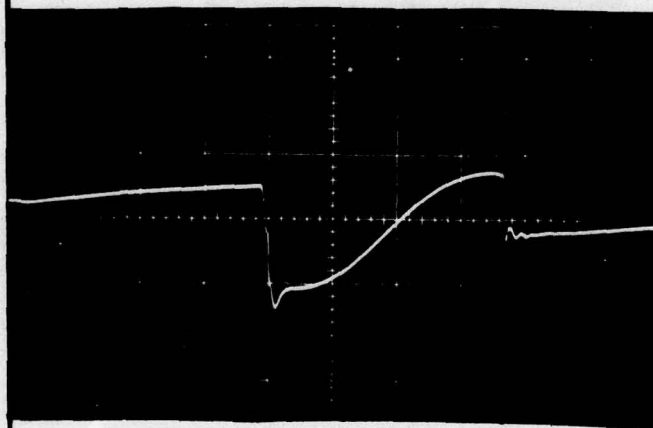
REVERSE BIAS TURN-OFF TIMES 400HZ, THREE PHASE



POWER CENTER
P₁ TURN-OFF

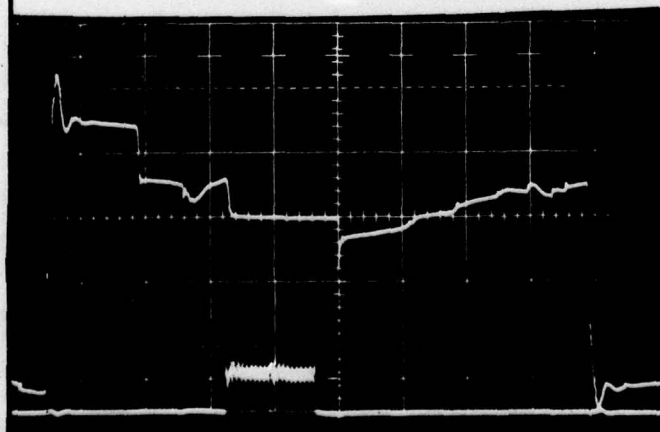
5V/DIV.
5μSEC/DIV.

20.6KW, PF=0.8



T- TURN-OFF

20V/DIV.
5μSEC/DIV.



R₃ TURN-OFF AS R₂ TURN-ON

50V/DIV.
30μSEC/DIV.

-0 R₃ GATE

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.
ITEM NO.
0006

PAGE 100 NO.
DESIGN
DATA

58

TITLE

PREPARED

CORRY

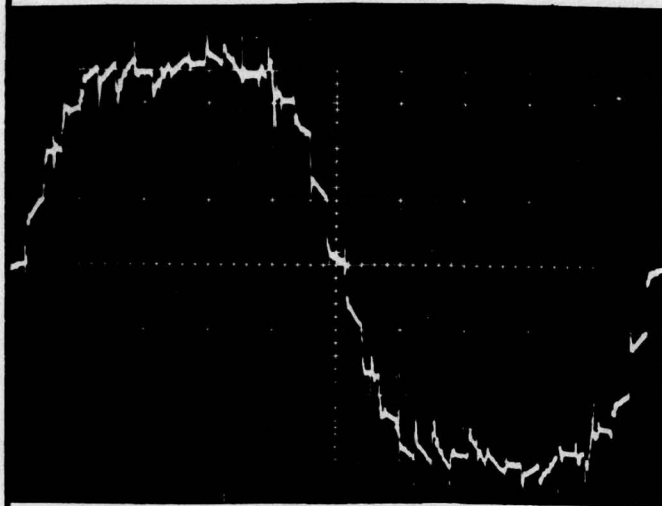
11/21/74

DATE

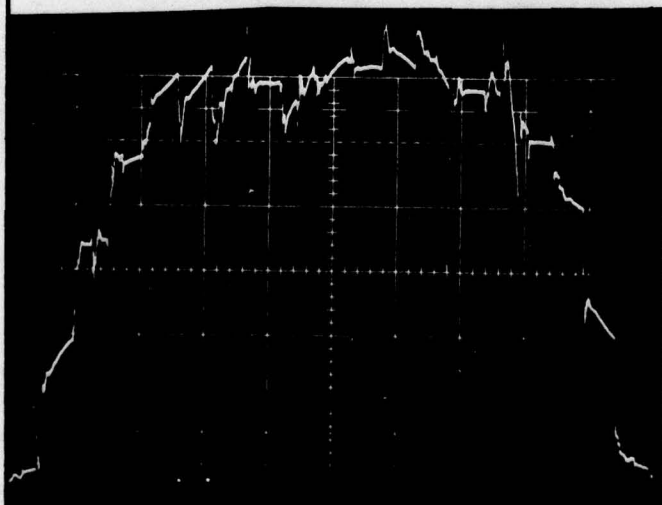
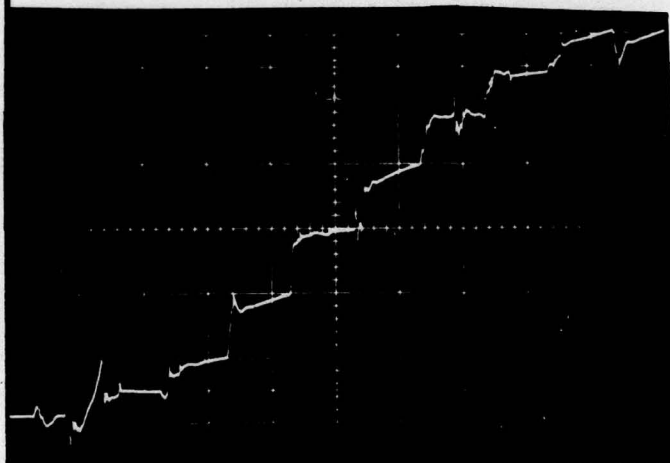
CHECKED

APPROVED

INVERTER BASIC VOLTAGES 400HZ NO LOAD



V_{c-n}



DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.

0006

PAGE

JOB NO.

DESIGN

DATA

PAGE

59

TITLE

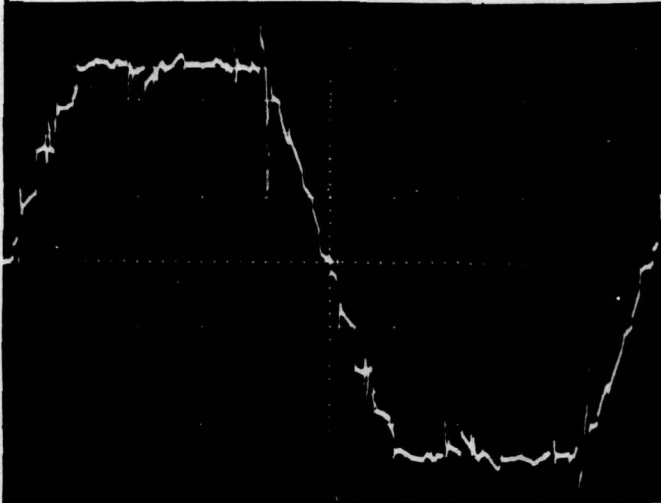
PREPARED

DATE

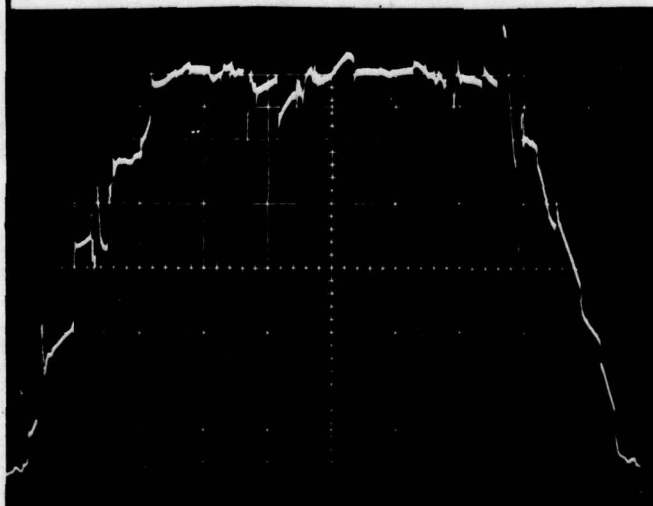
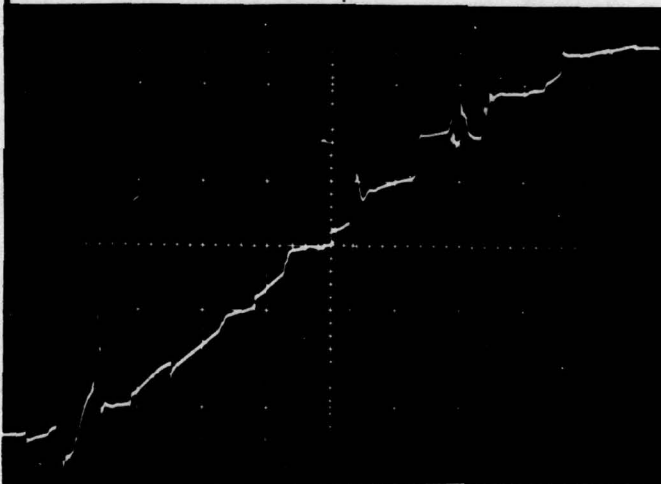
CHECKED

APPROVED

INVERTER BASIC VOLTAGES 400HZ 20.6KW, PF=0.8



V_{c-n}



DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.

0006

PAGE

DESIGN

DATA

PAGE

60

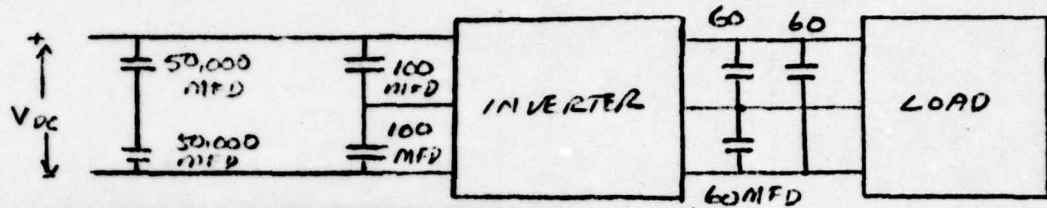
TITLE

PREPARED

DATE

CHECKED

APPROVED

TWO WIRE DC INPUT EXPERIMENT 400HZ, THREE PHASE

NO LOAD

100V/DIV

THD = 6.4%

 $V_{DC} = 285V_{DC}$

16KW, $Pf = 1.0$
THD = 5.8%

16KW, $Pf = 0.8$
THD = 4.2%

 $V_{DC} = 295V_{DC}$

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.

0006

PAGE

JOB NO.

DESIGN

DATA

PAGE

61

TITLE

PREPARED

DATE

CHECKED

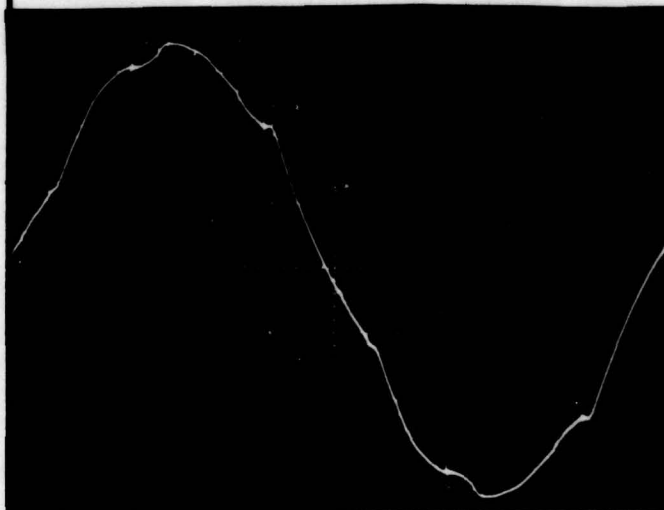
APPROVED



20.6KW, PF=0.8

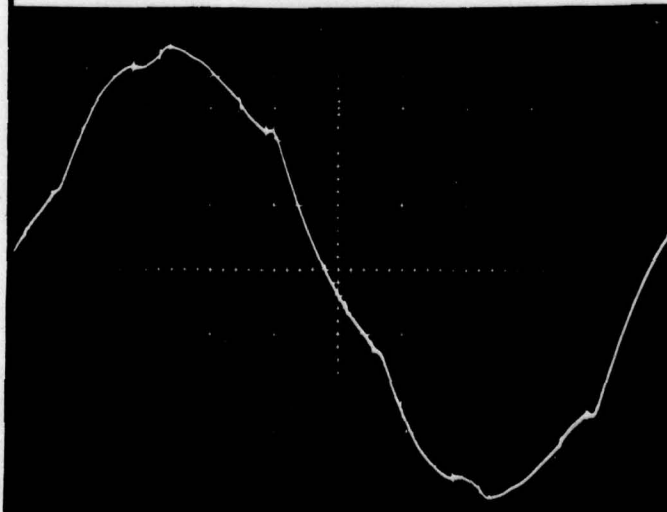
THD=4%

$V_{DC} = 296V_{DC}$



22.8KW, PF=0.8

THD=4.4%



24.8KW, PF=0.8

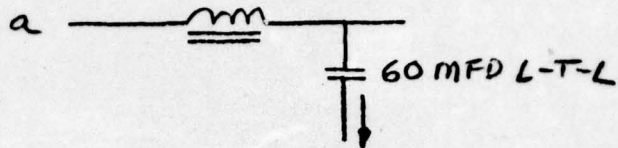
THD=5.2%

92 AMPS DC INPUT
CURRENT

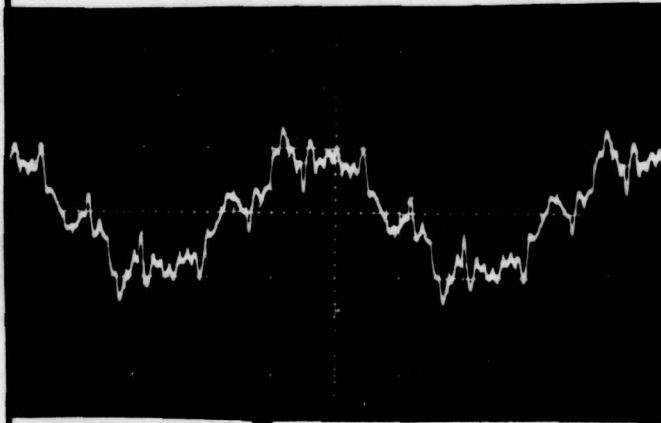
DISTRIBUTION:

TITLE

PREPARED
CORRY 11/21/79
CHECKED
APPROVED



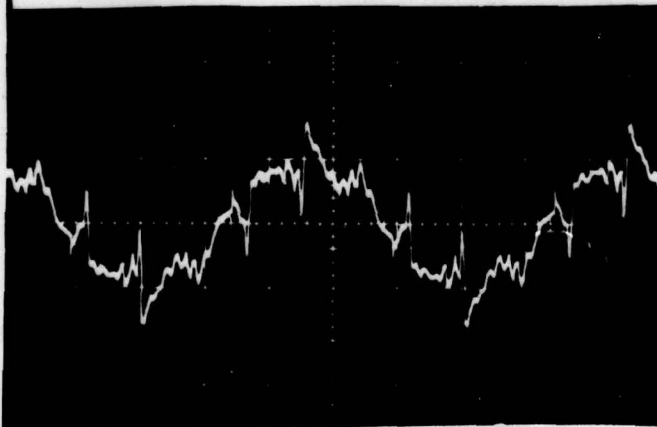
CURRENT THRU 60 MFD. CAPACITOR, 400 HZ



NO LOAD

50A/DIV.

500 μSEC/DIV.



20.6 KW, PF=0.8

DISTRIBUTION:

TITLE

PREPARED

CORRY

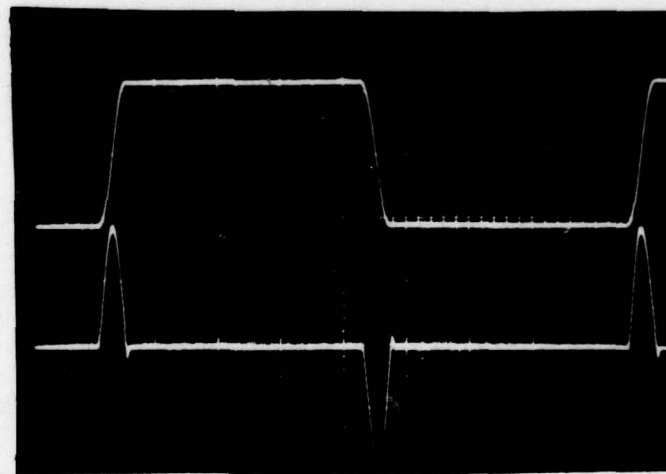
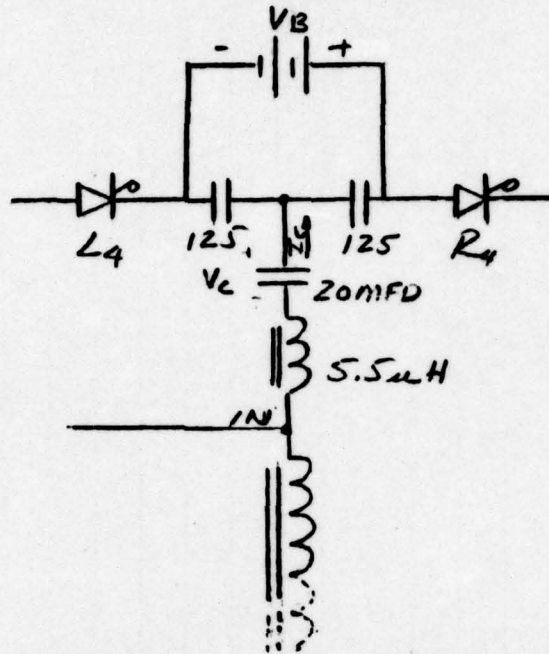
DATE

11/19/74

CHECKED

APPROVED

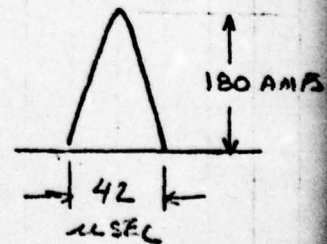
400 HZ POWER CENTER COMMUTATION



$V_B = 70 \text{ VDC}$
 $I_B = 5 \text{ AMPS}$

$V_C \text{ } 100 \text{ V/DIV}$

$I_C \text{ } 100 \text{ A/DIV.}$



$V_{C \text{ RMS}} = 113.5 \text{ Vrms}$

$I_{C \text{ RMS}} = 41.5 \text{ Arms.}$

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.

0006

PAGE

JOB NO.

THREE PHASE

PAGE

64

TITLE PERFORMANCE TESTS. ITEM NO. 0006, 15KVA
THREE PHASE FREQUENCY CONVERTER, IN
ACCORDANCE WITH ATTACHMENT NO. 2 CONTRACT
NO. DRAK02-72-3-0210 AND MK-STD-705B.

PREPARED

CORR-1

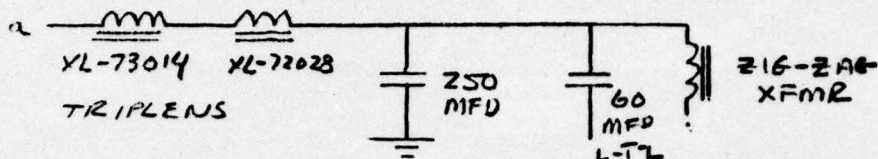
DATE

11/21/74

CHECKED

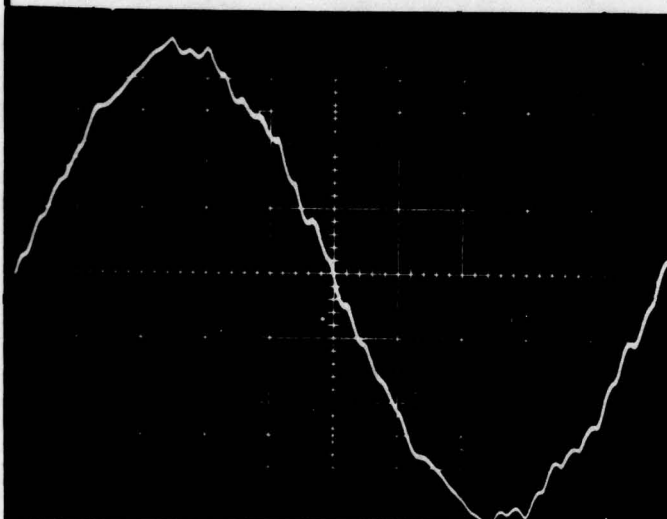
APPROVED

3.24.1.1 VOLTAGE OPERATING RANGE



60 HZ THREE PHASE

(BOOST COMMUTATION VOLTAGE = 66VDC
 $I_B = 6.5 \text{ AMPS DC}$)

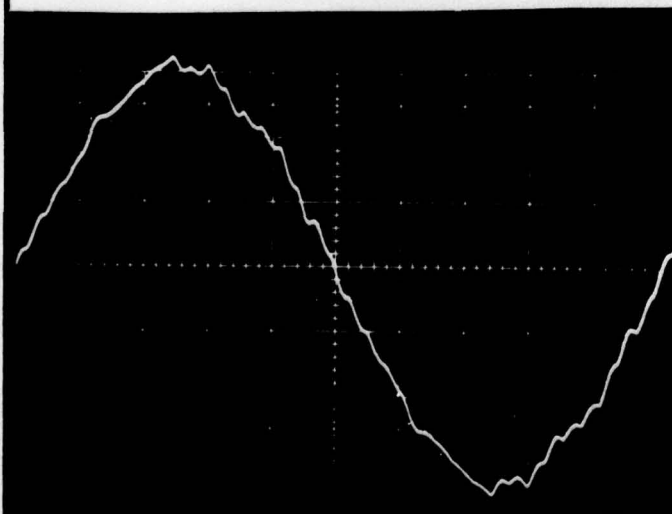


105 PERCENT OF
RATED VOLTAGE

L-T-N VOLTAGE
126V RMS
50V/DIV.

20.6KW, PF=0.8 LOAD
 $V_{DC} = 315 \text{ VDC}$; $I_{DC} = 83 \text{ AMPS DC}$

THD = 3.7%



95 PERCENT OF
RATED VOLTAGE
114V RMS

20.6KW, PF=0.8 LOAD
 $V_{DC} = 287 \text{ VDC}$; $I_{DC} = 76 \text{ AMPS DC}$

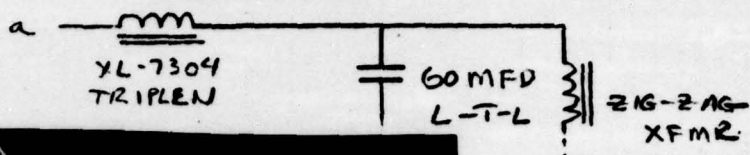
THD = 3.5%

DISTRIBUTION:

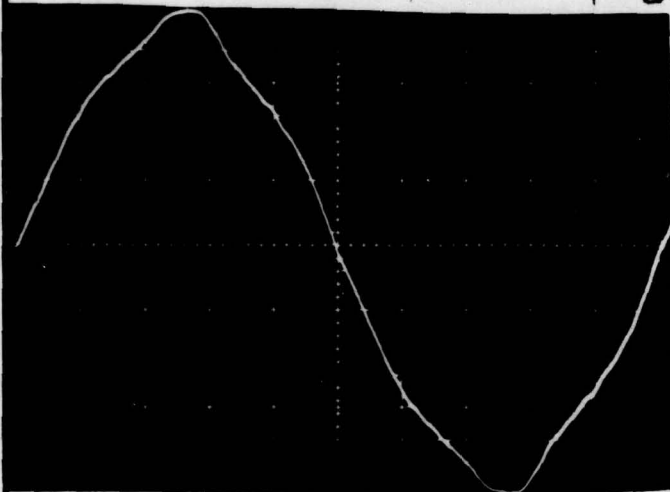
TITLE

PREPARED
CORRY 11/21/74
CHECKED
APPROVED

3.24.1.1 VOLTAGE OPERATING RANGE 400HZ THREE PHASE



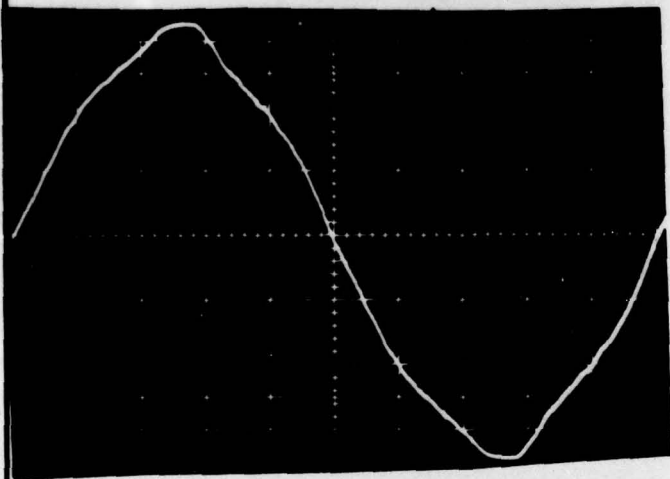
(COMMUTATION
BOOST VOLTAGE
30DC; $I_B = 2A$)



105 PERCENT OF
RATED VOLTAGE

L-T-N VOLTAGE
126 VRMS
50V/DIV.

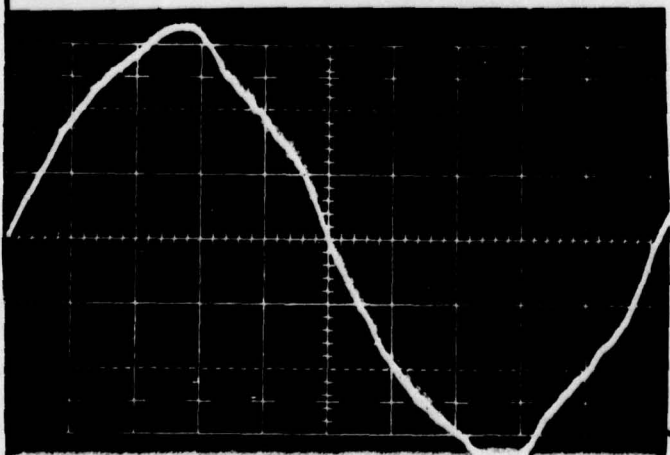
NO LOAD
THD = 4%



95 PERCENT OF
RATED VOLTAGE
114 VRMS

THD = 3.95% (WITHOUT P.C.
COMMUTATION C.T. XFMR)

NO LOAD



95 PERCENT OF
RATED VOLTAGE

THD = 4.3% (WITH P.C.
COMMUTATION C.T. XFMR)

NO LOAD

DISTRIBUTION:

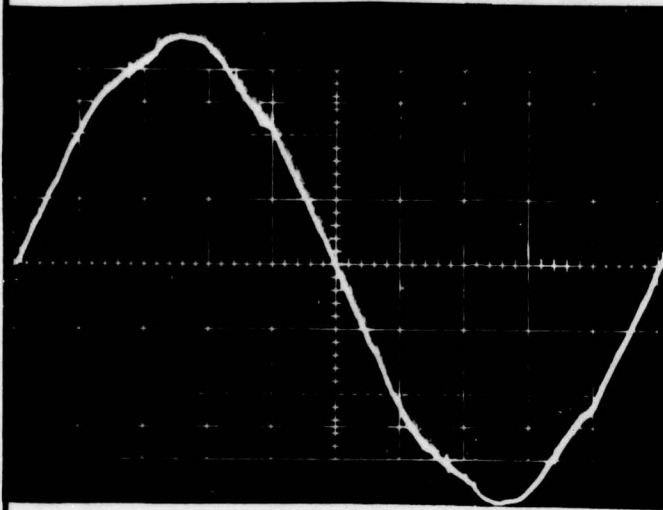
TITLE

PREPARED

DATE

CHECKED

APPROVED

3.24.11 VOLTAGE OPERATING RAISE100HZ, THREE PHASE

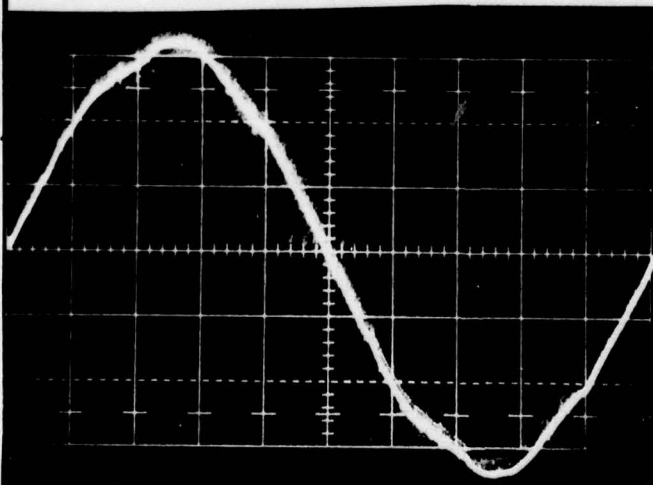
105 PERCENT OF
RATED VOLTAGE

L-T-N VOLTAGE

126VRMS

50V/DIV.

16KW, PF=0.8 LOAD
THD=2.14%



(P.C. REVERSE BIAS TURN-ON
TIME 18μSEC. WITHOUT COM-
MUTATION C.T. EXCISE. 29μSEC.
WITH C.T. X-ONER)

95 PERCENT OF
RATED VOLTAGE

114VRMS

16KW, PF=0.8 LOAD
THD=2.4%

DISTRIBUTION:

TITLE

PREPARED

CORY

DATE

11/11/74

CHECKED

APPROVED

3.24.13 VOLTAGE WAVEFORM

60 HZ THREE PHASE
LINE-TO-NEUTRAL VOLTAGES
NO LOAD

 V_{an}

120 Vrms

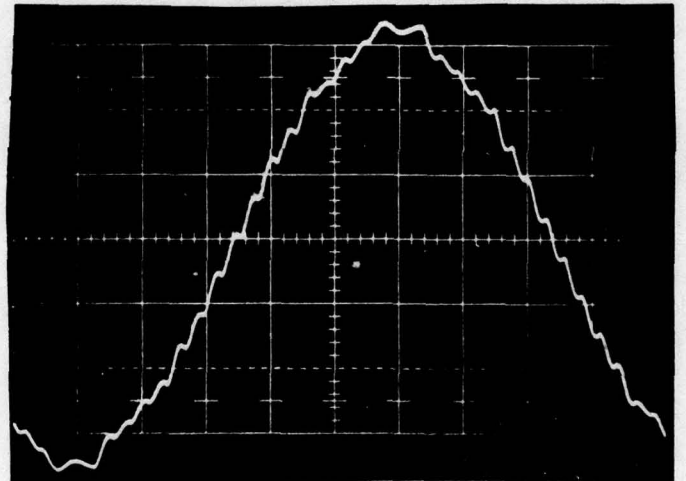
THD = 14%

50V/DIV.

 V_{bn}

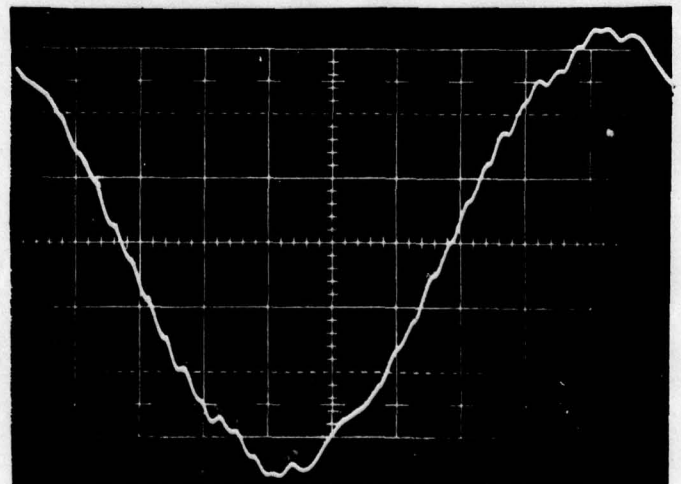
119.0 Vrms

THD = 4.1%

 V_{cn}

119.9 Vrms

THD = 3.75%

($V_{DC} = 285.3 \text{ VDC}$; $T_{R} = 2.0 \text{ ms}$)

DISTRIBUTION:

TITLE

PREPARED

DATE

CHECKED

APPROVED

COHEN

11/21/74

60HZ THREE PHASE
LINE-TO-LINE VOLTAGES

NO LOAD

V_{ab}

201 Vrms

THD = 4%

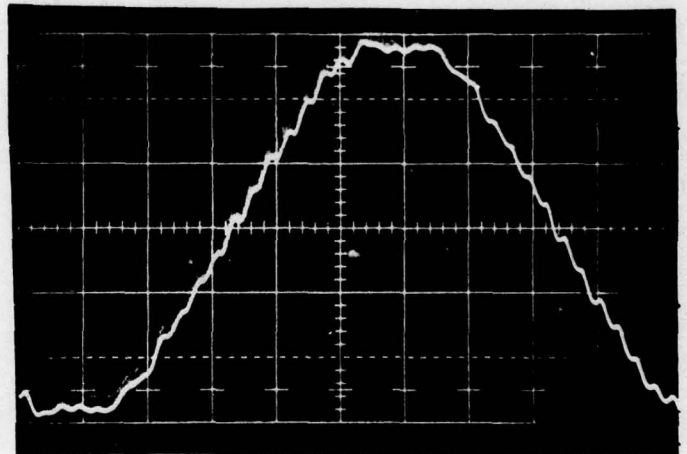
100V/DIV.



V_{bc}

207.9 Vrms

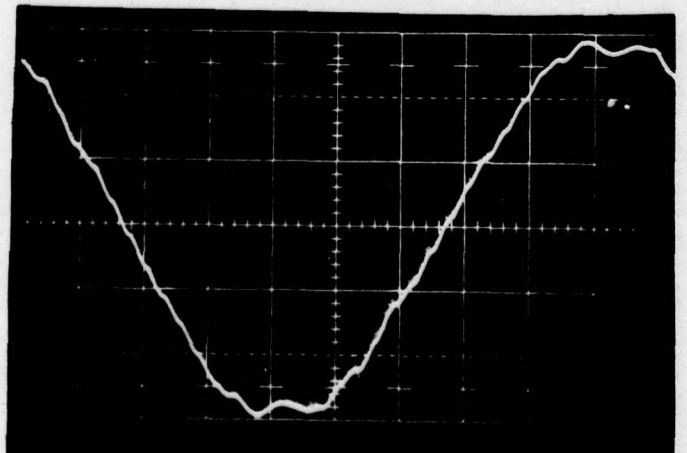
THD = 4.1%



V_{ca}

207.8 Vrms

THD = 3.75%



DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.
ITEM NO.
0006

PAGE JOB NO.
THREE PHASE

PAGE
69

TITLE

PREPARED CORRY DATE 11/22/74
CHECKED
APPROVED

60HZ THREE PHASE
LINE-TO-NEUTRAL VOLTAGES

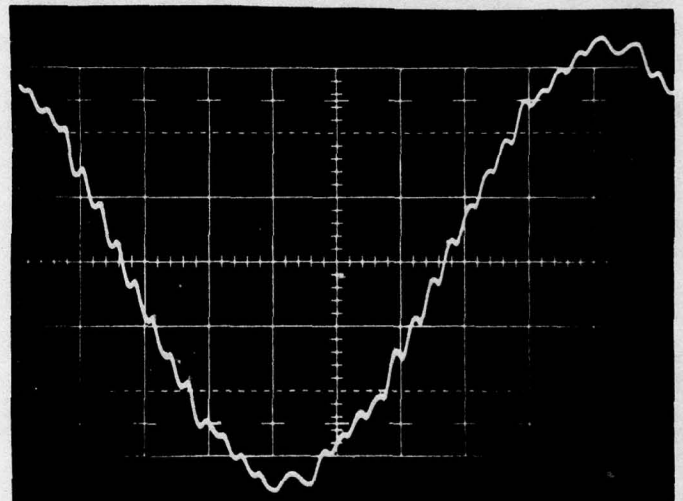
20.0KV, PF=0.8, LOAD

V_{an}
120.1 Vrms
THD = 3.9%

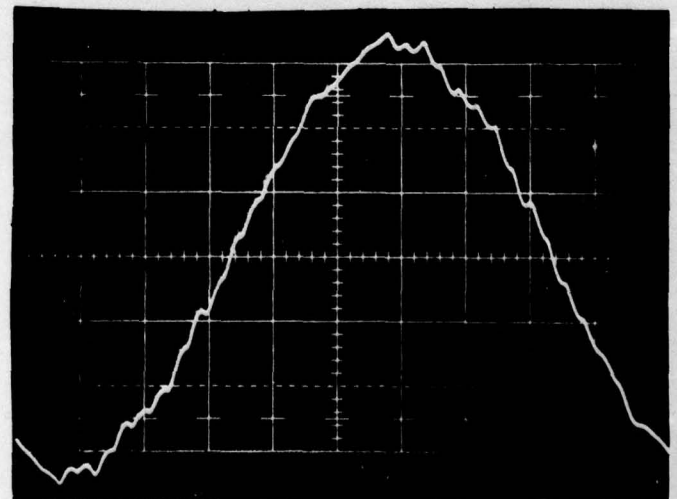
50V/1V



V_{bn}
120.6 Vrms
THD = 4.33%



V_{cn}
120.5 Vrms
THD = 3.6%



($V_{LL} = 20.25 \text{ kV}$, $I_L = 80 \text{ A}$)

DISTRIBUTION:

TITLE

PREPARED
CHECKED
APPROVED

60 HZ THREE PHASE
LINE-TO-LINE VOLTAGES

20.6KW, PF=0.8 LOAD

V_{ab}
207.0Vrms

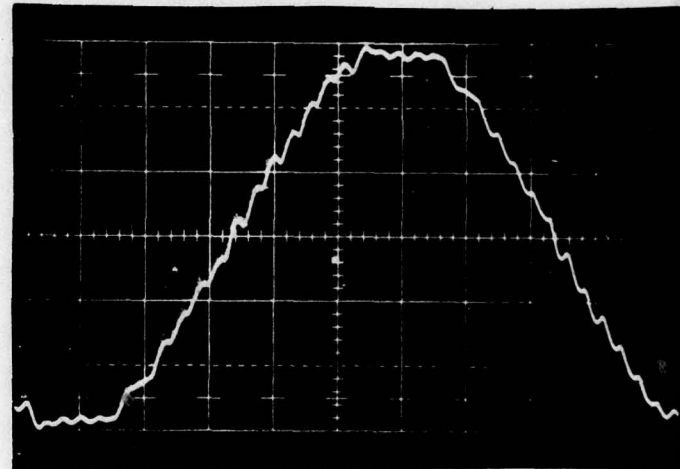
THD= 3.9%

100V/DIV.



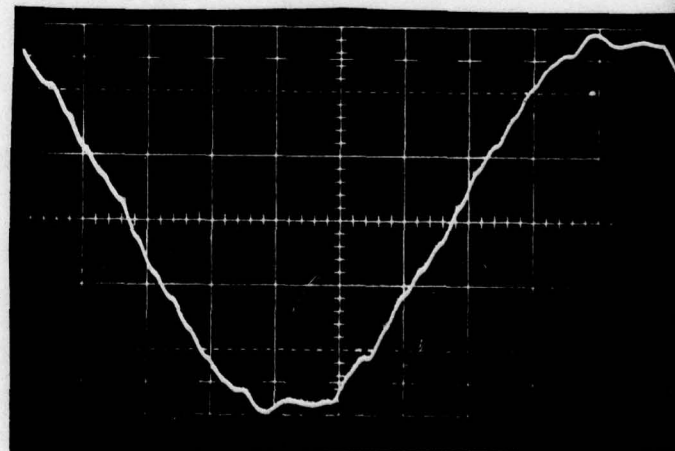
V_{bc}
209Vrms

THD= 4.33%



V_{ca}
207.2Vrms

THD= 3.6%



DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

ITEM NO.
0006

THREE PHASE

71

TITLE

PREPARED

DATE

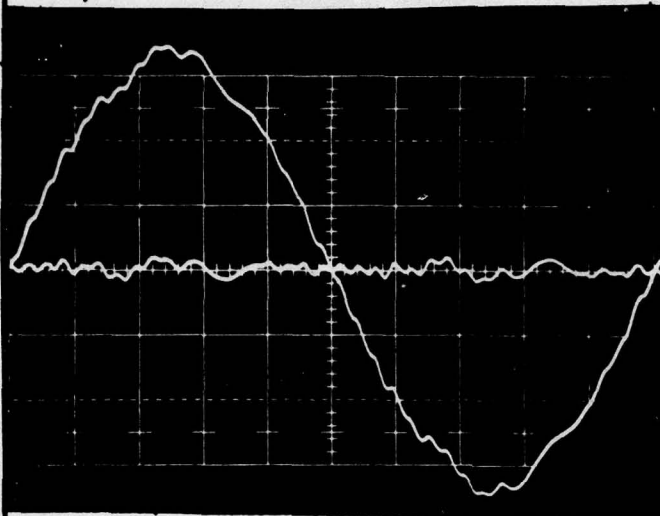
CORRY 11/22/74

CHECKED

APPROVED

DEVIATION FACTOR

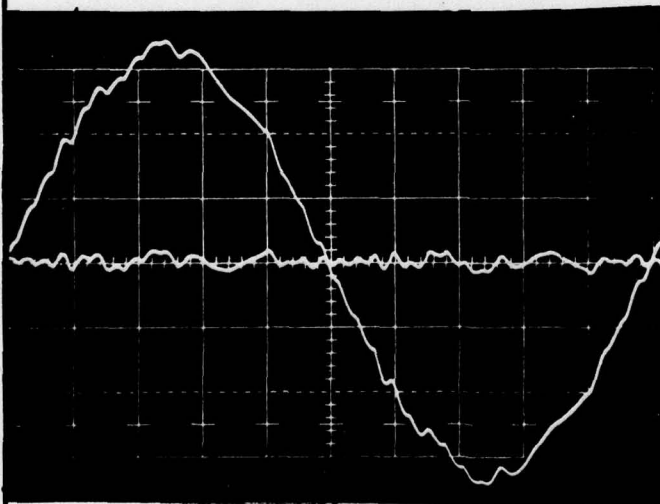
60HZ THREE PHASE
LINE-TO-NEUTRAL VOLTAGES



NO LOAD

VOLTAGE INTO 60HZ NOTCH
FILTER COMPARED TO
VOLTAGE OUT OF FILTER

50V / DIV.



16KW, 1F-0.8 LOAD

DISTRIBUTION:

DELCO ELECTRONICS
GENERAL MOTORS CORPORATION

REPORT NO.
ITEM NO.
0006

PAGE JOB NO.
THREE PHASE

PAGE
72

TITLE

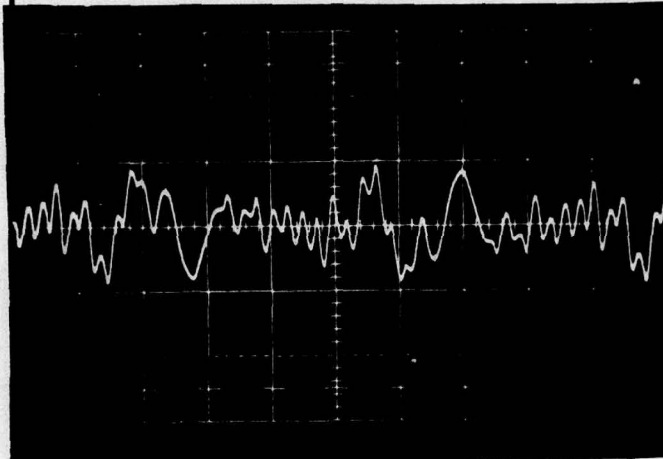
PREPARED
CORRY 11/21/74

DATE

CHECKED

APPROVED

DEVIATION FACTOR



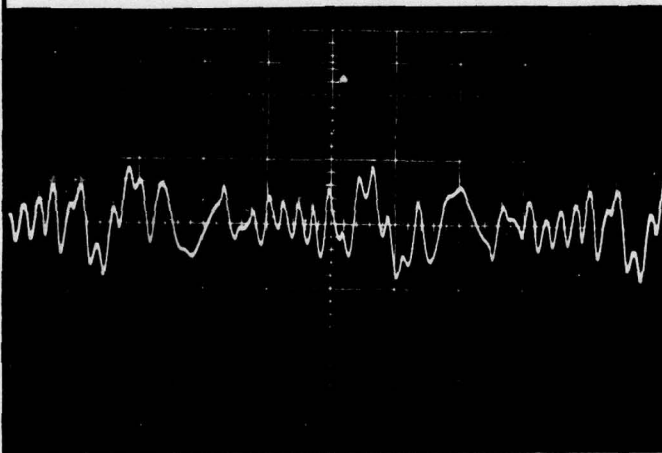
60 HZ THREE PHASE
LINE-TO-NEUTRAL VOLTAGES

OUTPUT OF 60 HZ NOTCH
FILTER

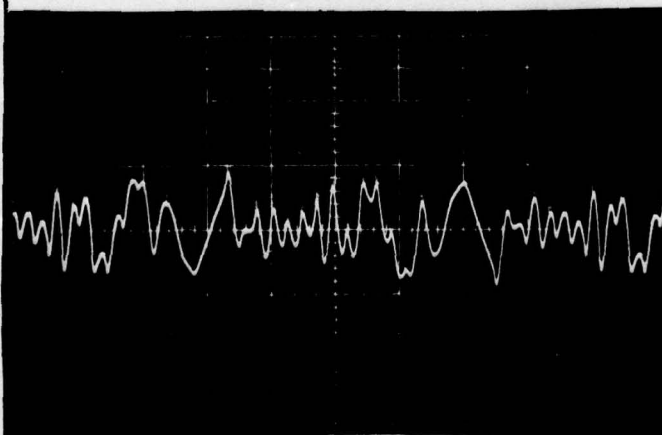
NO LOAD

10V / DIV

200 / DIV



16KW, PF = 1.0



16KW, PF = 0.8

DISTRIBUTION:

TITLE

PREPARED

CORY

DATE

11/22/74

CHECKED

APPROVED

400 HZ THREE PHASE
LINE-TO-NEUTRAL VOLTAGES

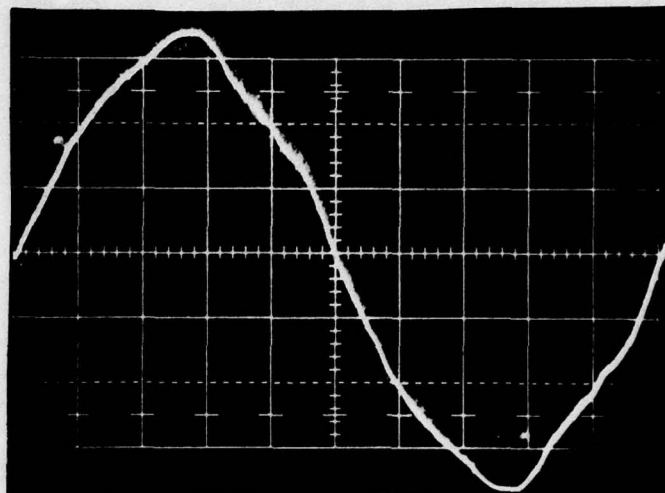
NO LOAD

V_{an}

120 Vrms

THD = 11.2%

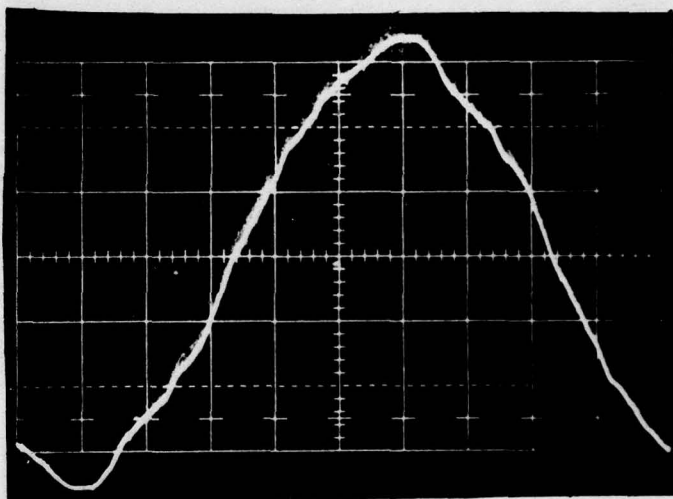
50V/DIV.



V_{bn}

119.5 Vrms

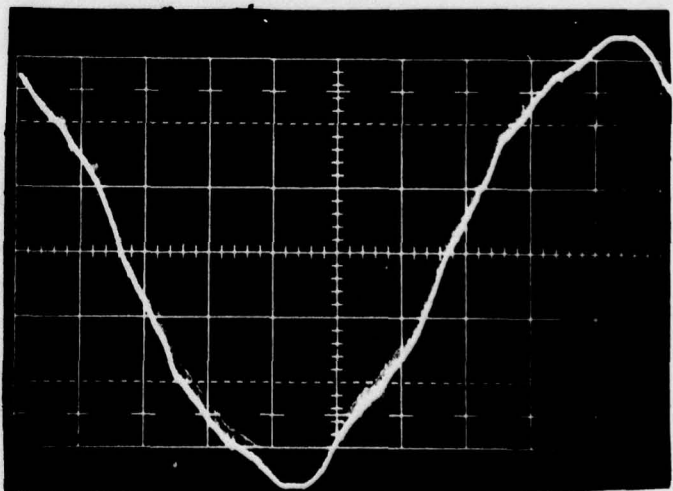
THD = 3.9%



V_{cn}

119.9 Vrms

THD = 4.1%



($V_{DC} = 280V$ DC, $I_{DC} = 50A$)
($V_{R_{DC}} = 20V$ DC, $T_{DC} = 30^\circ C$)

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.
0006

PAGE

JOB NO.

THREE PHASE

PAGE

74

TITLE

PREPARED

CORRY

DATE

11/24/74

CHECKED

APPROVED

400 HZ THREE PHASE
LINE-TO-LINE VOLTAGES

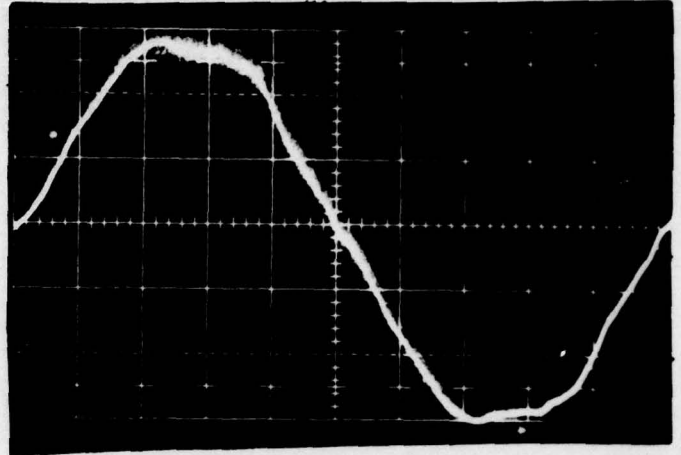
NO LOAD

V_{ab}

207Vrms

THD = 4.2%

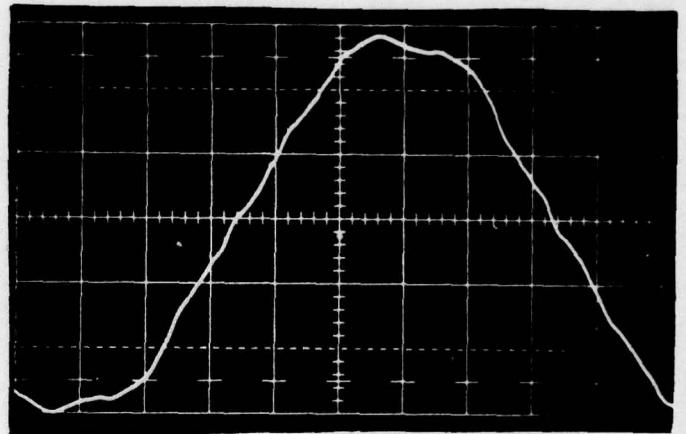
100V/DIV.



V_{bc}

206.5Vrms

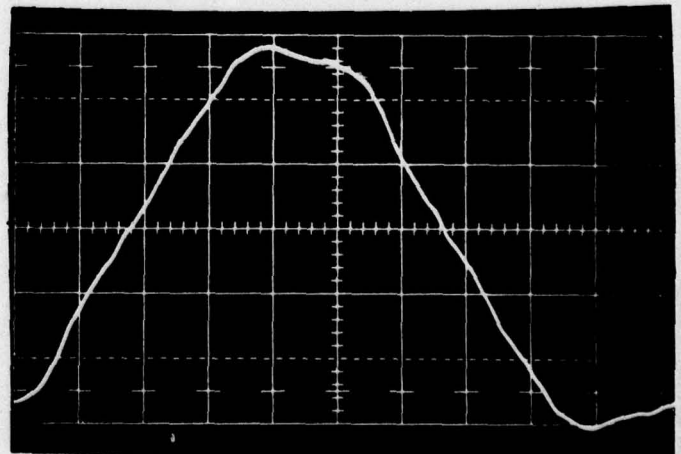
THD = 3.9%



V_{ca}

207.5Vrms

THD = 4.1%



DISTRIBUTION:

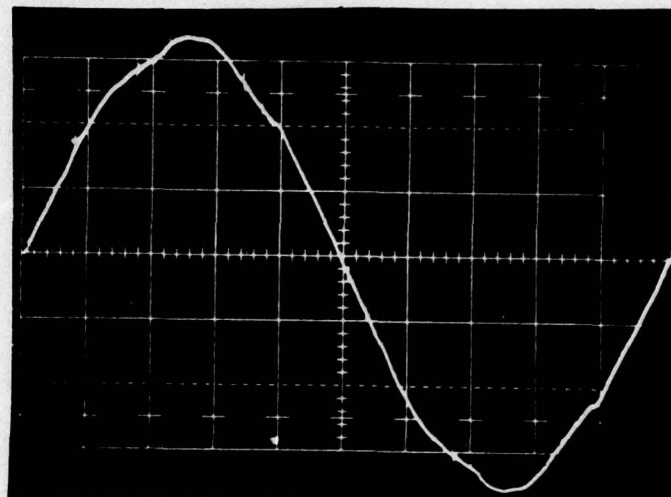
TITLE

PREPARED
COREY 11/22/74
CHECKED
APPROVED

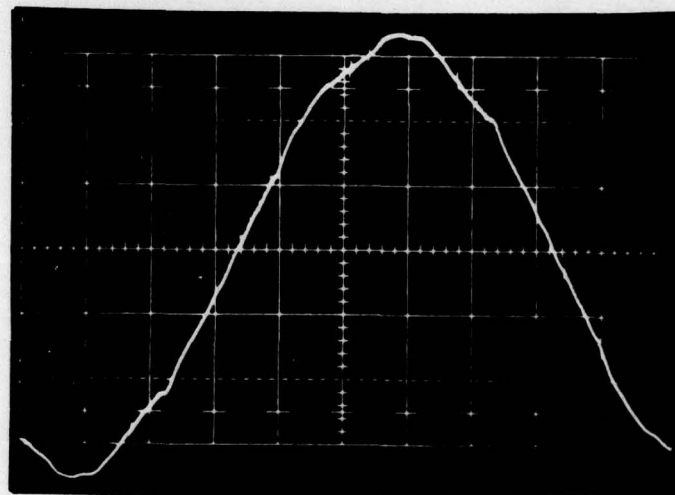
400HZ THREE PHASE
LINE-TO-NEUTRAL VOLTAGES

16KW, PF=0.1 LOAD

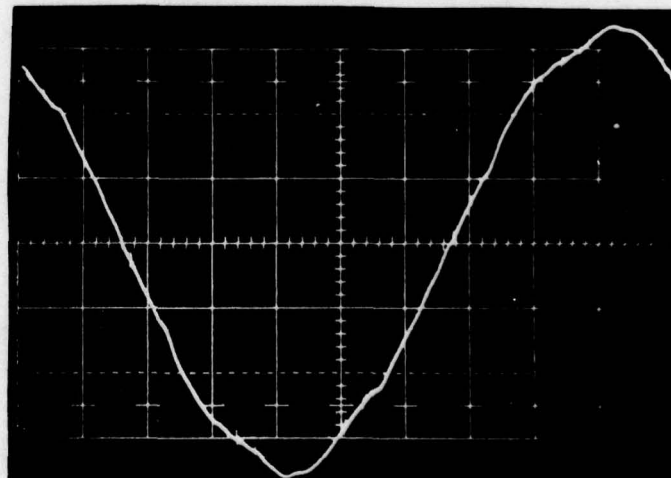
V_{an}
120 Vrms
THD=2.48%



V_{bn}
119.3 Vrms
THD=2.19%



V_{cn}
120 Vrms
THD=2.7%



($V_{dc} = 295.5VDC$; $I_{dc} = 62A$)
($V_{P001T} = 30V$ $I_{dc} = 3A$)

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.
0006

PAGE

JOB NO.

THREE PHASE

PAGE

76

TITLE

PREPARED

CORRY

DATE

11/22/79

CHECKED

APPROVED

400 HZ THREE PHASE
LINE-TO-LINE VOLTAGES

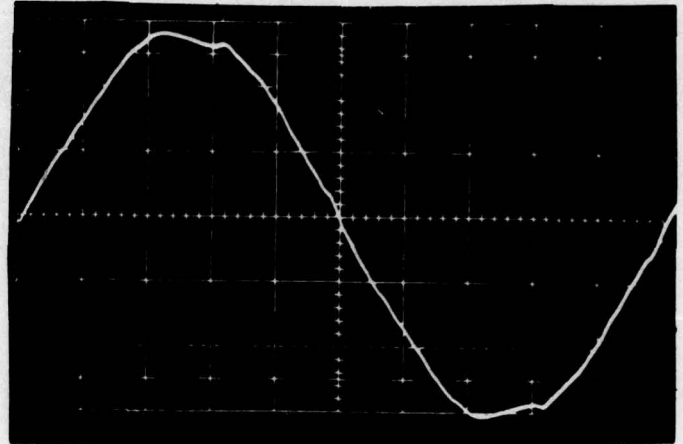
16KW, PF=0.8 LOAD

V_{ab}

206 V RMS

THD= 2.48%

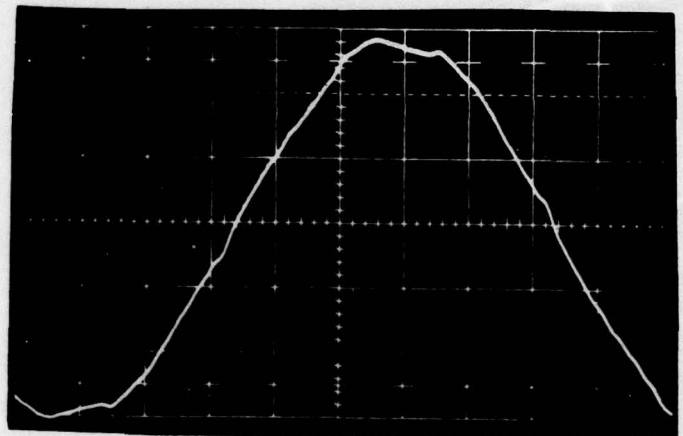
100V/DIV



V_{bc}

207 V RMS

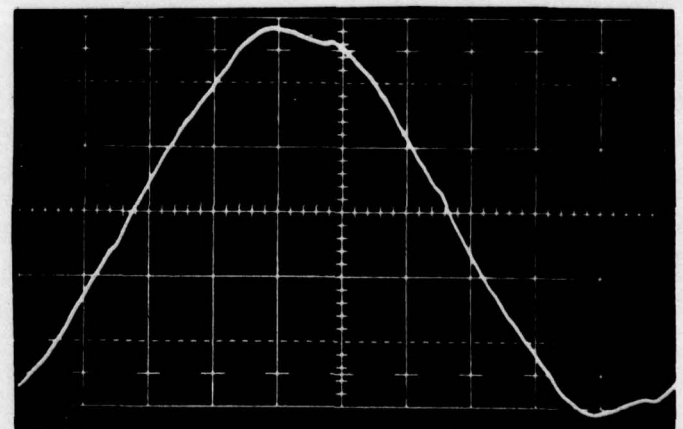
THD= 2.19%



V_{ca}

206.5 V RMS

THD= 2.7%



DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.
0006

PAGE

JOB NO.

THREE PHASE

PAGE

77

TITLE

PREPARED

CORRY 11/11/79

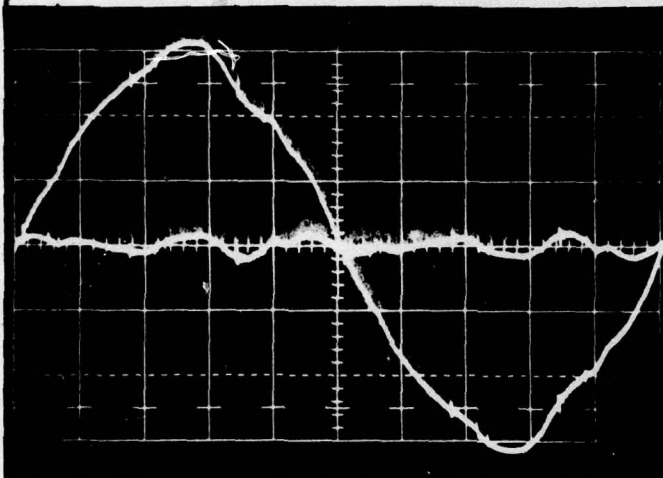
DATE

CHECKED

APPROVED

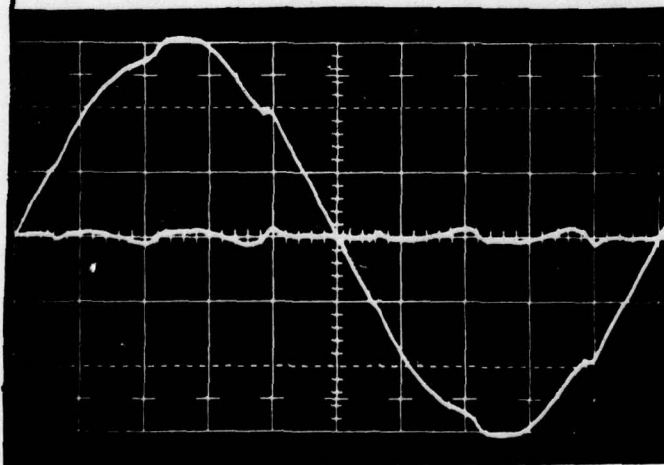
DEVIATION FACTOR

400 HZ THREE PHASE
LINE-TO-NEUTRAL VOLTAGES



NO LOAD

RELATIVE VOLTAGES
INTO AND OUT OF
400 HZ NOTCH FILTER
10:1 ATTENUATION
5V/DIV.

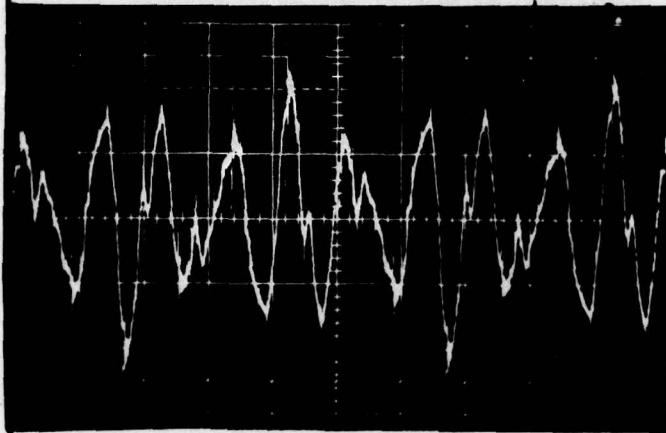


1.6KW, PF=0.8

DISTRIBUTION:

DELCO ELECTRONICS GENERAL MOTORS CORPORATION	REPORT NO. ITEM NO. 0006	PAGE THREE PHASE	JOB NO. 78
	TITLE		
PREPARED CORRY		DATE 1/22/70	
CHECKED		APPROVED	

DEVIATION FACTOR



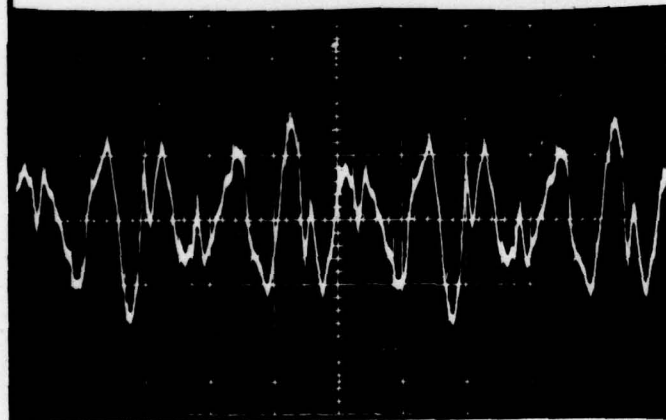
400 HZ THREE PHASE
LINE-TO-NEUTRAL VOLTAGES

OUTPUT OF 400 HZ NOTCH
FILTER

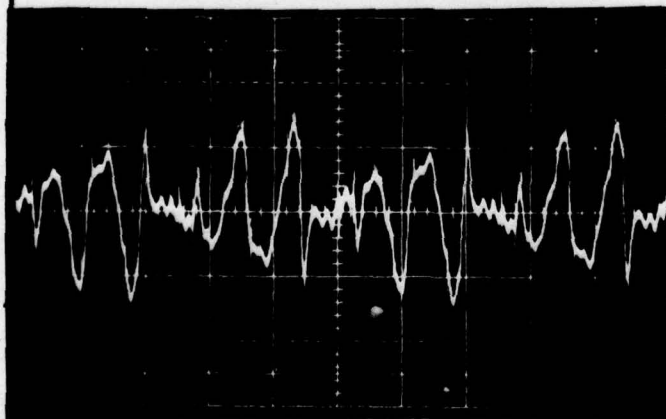
NO LOAD

0.5V/DIV.

500 μsec/DIV.



1600, PF=1.0



1600, PF=0.8

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.

0006

PAGE

SUB NO.

THREE PHASE

PAGE

79

TITLE

PREPARED

DATE

CORY 11/22/79

CHECKED

APPROVED

MEASUREMENTS OF INDIVIDUAL HARMONICS

60 HZ THREE PHASE

11KW, PF= 0.8 LOAD

HARMONIC NUMBER	FREQUENCY HZ	PERCENT OF FUNDAMENTAL	
		L-T-N	L-T-L
1	60	100	100
3	180	0.20	0.30
5	300	1.10	1.25
7	420	1.60	1.50
11	660	1.95	1.60
13	780	0.60	0.26
15	900	—	0.26
17	1020	1.60	1.60
19	1140	0.30	0.72
21	1260	—	0.22
23	1380	—	0.28
25	1500	0.20	0.58
29	1740	0.28	1.52
31	1860	—	0.20
35	2100	1.20	1.70
37	2220	0.70	1.20

ONLY HARMONICS $\geq 0.2\%$ RECORDED

DISTRIBUTION:

DELCO ELECTRONICS GENERAL MOTORS CORPORATION	REPORT NO. ITEM NO. 0006	PAGE	JOB NO. THREE PHASE	PAGE 80
	TITLE		PREPARED CORY 11/22/79	DATE
		CHECKED		
		APPROVED		

MEASUREMENTS OF INDIVIDUAL HARMONICS

400 HZ THREE PHASE 11KW, PF=0.8 LOAD

HARMONIC NUMBER	FREQUENCY HZ	PERCENT OF FUNDAMENTAL	
		L-T-N	L-T-L
1	400	100	100
5	2000	2.4	2.35
7	2800	1.83	1.50
11	4400	0.63	0.80
13	5200	0.78	1.10
17	6800	0.34	0.42
19	7600	0.43	0.60
23	9200	0.31	0.38
25	10,000	0.21	0.33
29	11,600	0.21	0.24
35	14,000	0.22	0.30

DISTRIBUTION:

DELCO ELECTRONICS GENERAL MOTORS CORPORATION	REPORT NO. ITEM NO. 0006	PAGE	JOB NO. THREE PHASE	PAGE 81
	TITLE		PREPARED CORY 11/22/74	DATE
		CHECKED		
		APPROVED		

DC VOLTAGE COMPONENT

400 HZ, THREE PHASE			
	MV D.C.		
	NO LOAD	16KW PF=1.0	16KW PF=0.8
V _{an}	23.8	6.8	17.5
V _{bn}	15.0	0.2	27.9
V _{cn}	8.3	1.2	12.6
60 HZ, THREE PHASE			
V _{an}	3.4	20.0	20.0
V _{bn}	10.0	24.0	38.0
V _{cn}	9.5	17.0	37.0

DISTRIBUTION:

DELCO ELECTRONICS GENERAL MOTORS CORPORATION	REPORT NO. ITEM NO. 0006	PAGE	JOB NO. THREE PHASE	PAGE 82
	TITLE		PREPARED CORRY	DATE 11/22/79
		CHECKED		
		APPROVED		

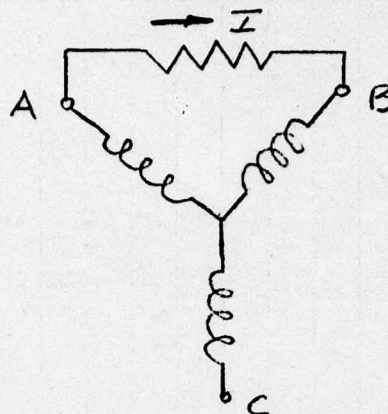
3.24.1.4 PHASE VOLTAGE BALANCE

FREQ. Hz	LOAD KW	P.F.	V _{an} V _{rms}	V _{bn} V _{rms}	V _{cn} V _{rms}	V _{ab} V _{rms}	V _{bc} V _{rms}	V _{ca} V _{rms}
60	0	—	120	119.9	119.9	208	207.9	207.8
60	20.6	0.8	120.1	120.6	120.5	207.0	209	207.2
400	0	—	120	119.5	119.9	207	206.5	207.5
400	16	0.8	120	119.3	120	206	207	206.5

DISTRIBUTION:

DELCO ELECTRONICS GENERAL MOTORS CORPORATION	REPORT NO. ITEM NO. 0006	PAGE	JOB NO. THREE PHASE	PAGE 83
	TITLE		PREPARED CORY 11/22/79	DATE
		CHECKED		
		APPROVED		

3.24.1.5 EFFECT OF UNBALANCED LOAD (3PHASE)



60 HZ

$I = 12 A_{rms}$

V_{ab}	206 V_{rms}
V_{bc}	206
V_{ca}	201

V_{an}	117.2
V_{bn}	117.0
V_{cn}	120

MAXIMUM
L-T-L VOLTAGE
DIFFERENCE 5.0 V_{rms}

$$\frac{5.0}{206} \times 100 = 2.42\%$$

400 HZ

• $I = 12 A_{rms}$

207 V_{rms}
203
208

121.2
119
118.5

5.0 V_{rms}

$$\frac{5.0}{208} \times 100 = 2.4\%$$

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.

0006

PAGE

JOB NO.

THREE PHASE

PAGE

84

TITLE

PREPARED

DATE

CORY

11/22/77

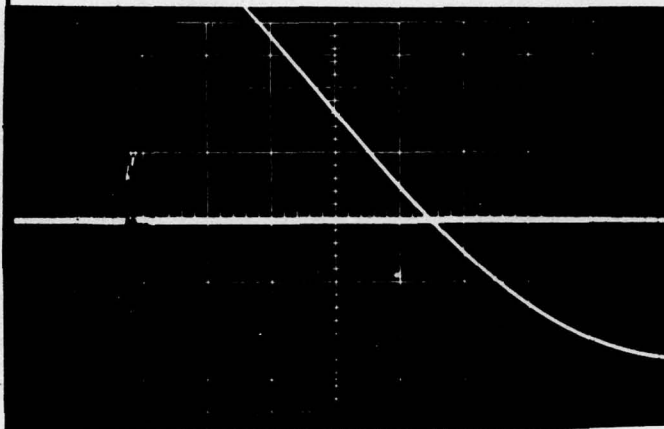
CHECKED

APPROVED

3.24.16 PHASE ANGLE BALANCE

60HZ BALANCED LOAD

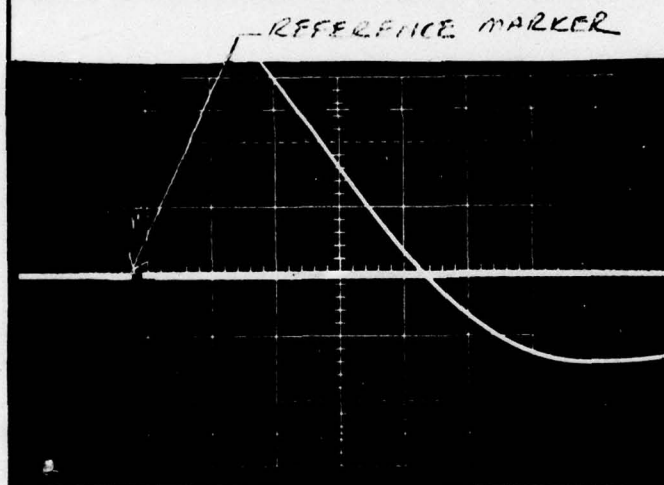
L-T-N VOLTAGES

NO LOAD

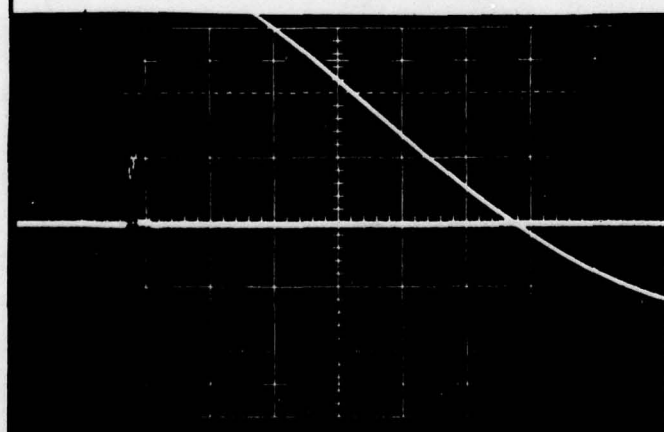
PHASE A

0 CROSS-OVER

↓ 5V/DIV
→ 1.09°/DIV.
(50μSEC/DIV)



PHASE B



PHASE C

DISTRIBUTION:

DELCO ELECTRONICS
GENERAL MOTORS CORPORATION

REPORT NO.
ITEM NO.
0006

PAGE JOB NO.
THREE PHASE 85

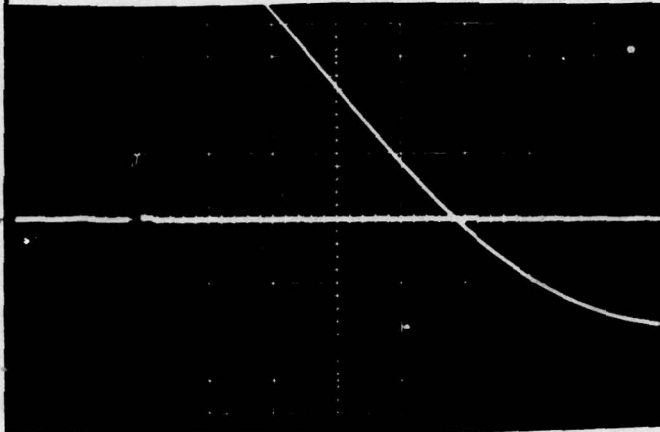
TITLE

PREPARED
CORREY 11/22/79
CHECKED
APPROVED

60 HZ BALANCED LOAD
L-T-13 VOLTAGE

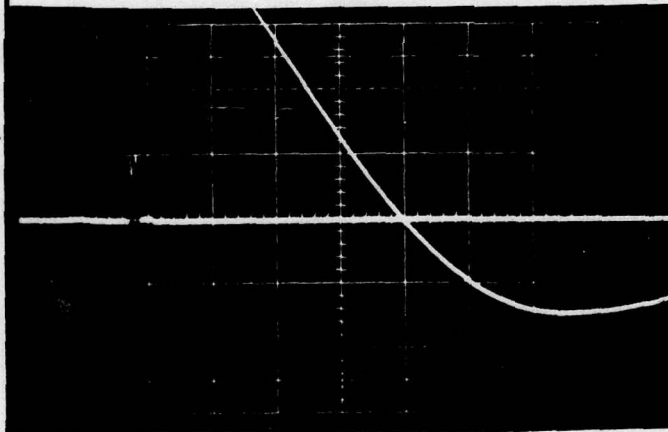
16KW, PF = 1.0 LOAD

PHASE A

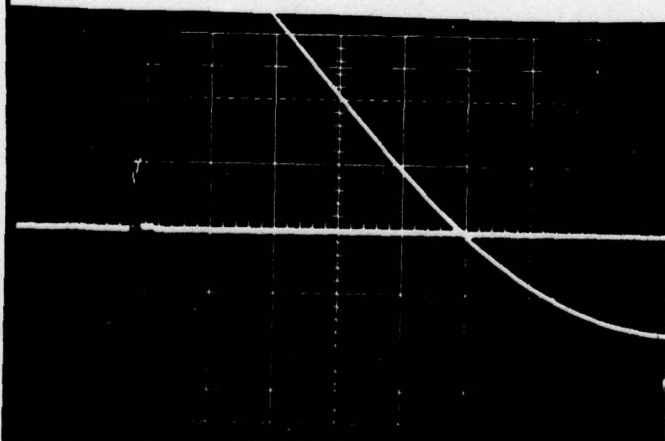


↑ 5V/DIV.
→ 1.09°/DIV.
(50μSEC/DIV.)

PHASE B



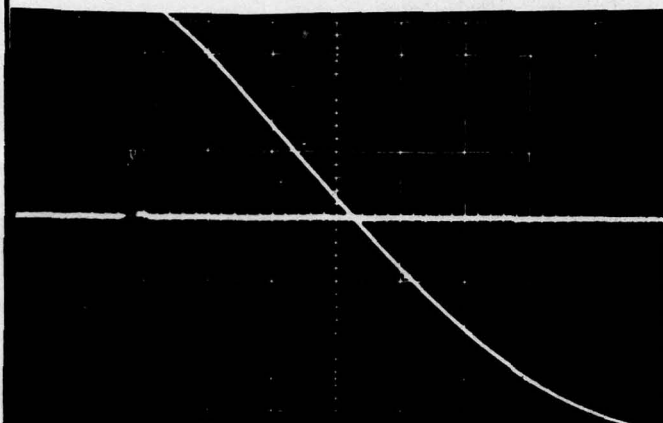
PHASE C



DISTRIBUTION:

DELCO ELECTRONICS GENERAL MOTORS CORPORATION	REPORT NO. ITEM NO. 0006	PAGE	JOB NO. THREE PHASE	PAGE 86
	TITLE		PREPARED CORY	DATE 11/22/74
		CHECKED		
		APPROVED		

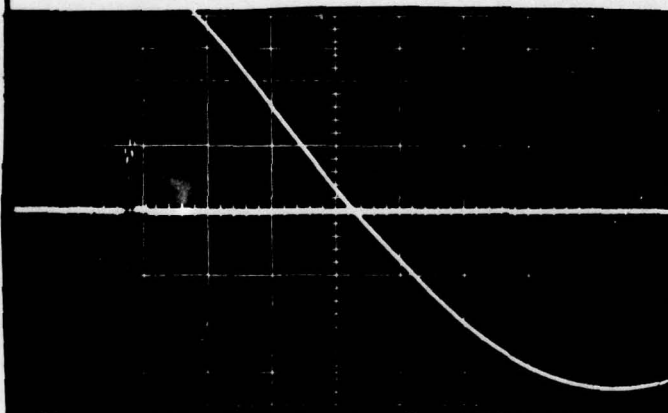
60 HZ BALANCED LOAD
L-T-N VOLTAGES



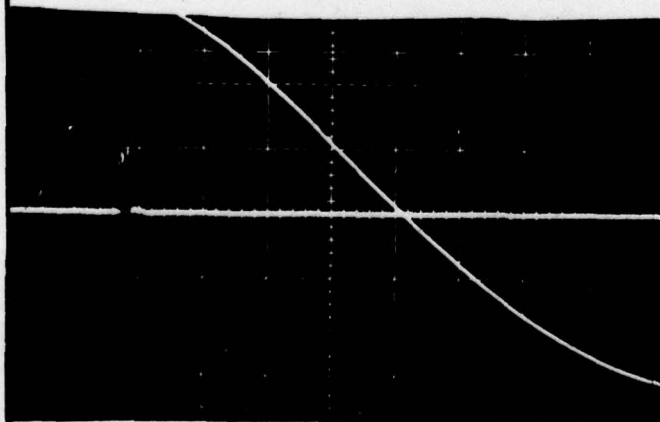
16KW, PF=0.8 LOAD

PHASE A

↑ 5V/DIV.
↔ 1.09°/DIV.
(50μSEC/DIV.)



PHASE B

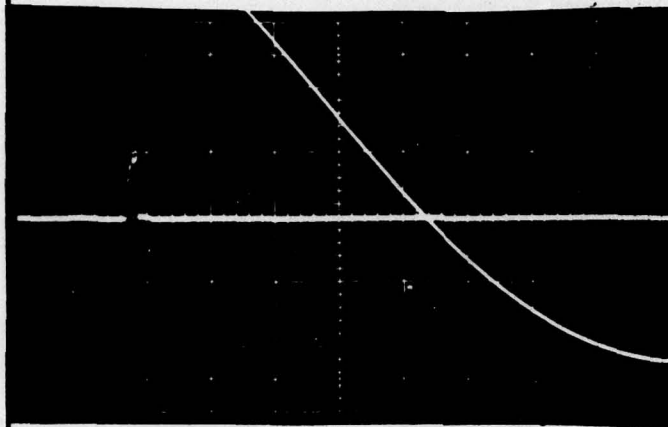


PHASE C

DISTRIBUTION:

DELCO ELECTRONICS GENERAL MOTORS CORPORATION	REPORT NO. ITEM NO. 0006	PAGE	JOB NO. THREE PHASE	PAGE 87
	TITLE		PREPARED CORRY	DATE 11/24/74
		CHECKED		
		APPROVED		

60 HZ 25 PERCENT UNBALANCED LOAD
AS DESCRIBED IN 3,24.1.5

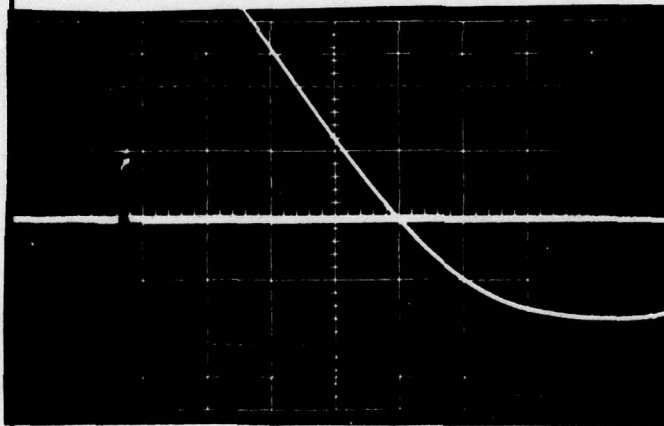


L-T-N VOLTAGES

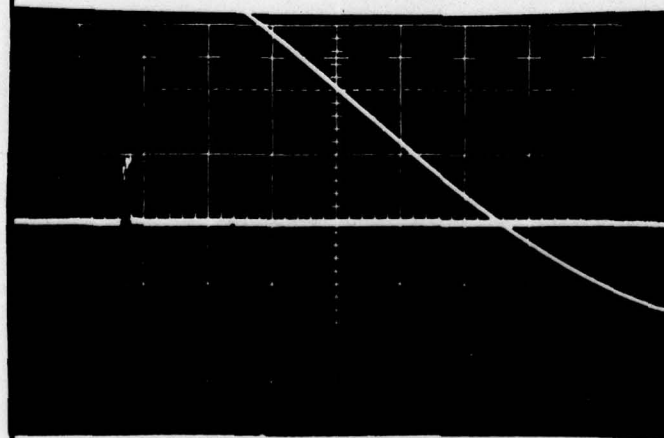
PHASE A

↓ 5V/DIV.
→ 1.07°/DIV.

4.4 KW, PF=1.0 LOAD
PHASES A-B



PHASE B



PHASE C

DISTRIBUTION:

DELCO ELECTRONICS GENERAL MOTORS CORPORATION	REPORT NO. ITEM NO. 0006	PAGE	JOB NO. THREE PHASE	PAGE 88
	TITLE		PREPARED CORY 11/24/79	DATE
		CHECKED		
		APPROVED		

400 HZ BALANCED LOAD
L-T-N VOLTAGES

NO LOAD

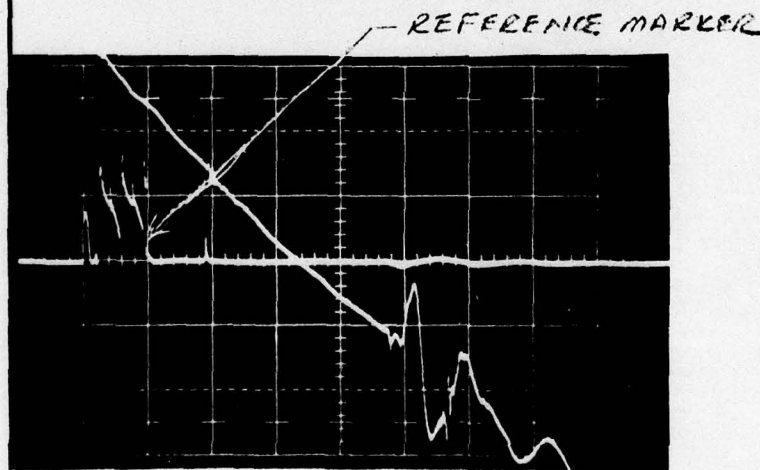


PHASE A

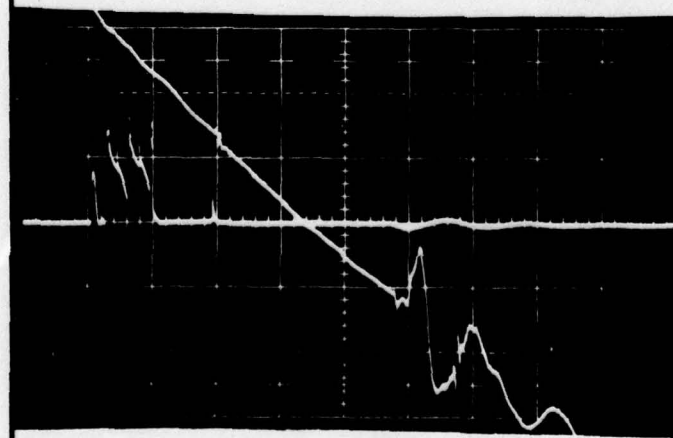
-O CROSS OVER

↓ 5V / DIV.

← 1.44° / DIV.
(10 μSEC / DIV.)



PHASE B

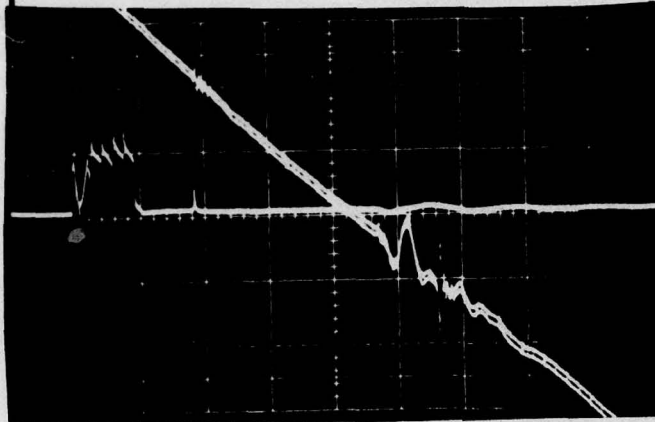


PHASE C

DISTRIBUTION:

DELCO ELECTRONICS GENERAL MOTORS CORPORATION	REPORT NO. ITEM NO. 0006	PAGE JOB NO. THREE PHASE	PAGE 89
	TITLE		DATE CORRY 11/24/79
		CHECKED	
		APPROVED	

400HZ BALANCED LOAD
L-T-N VOLTAGES

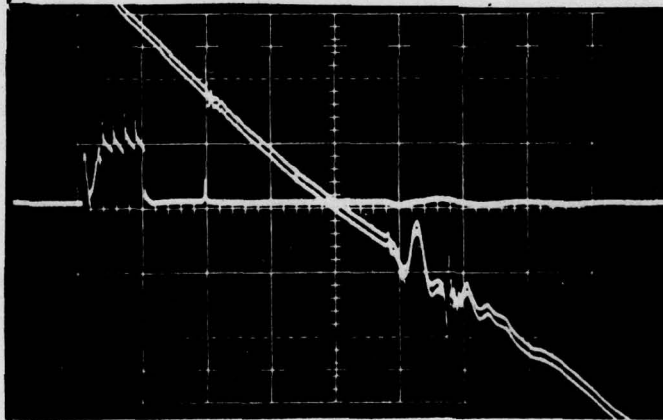


16KW, PF=1.0 LOAD

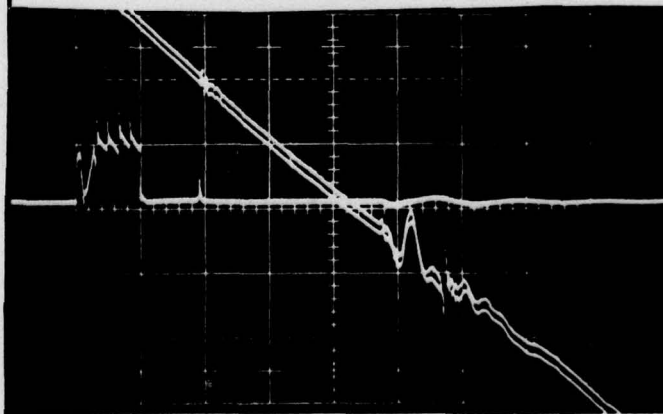
PHASE A

↓ 5V/DIV.

← 1.44°/DIV.



PHASE B



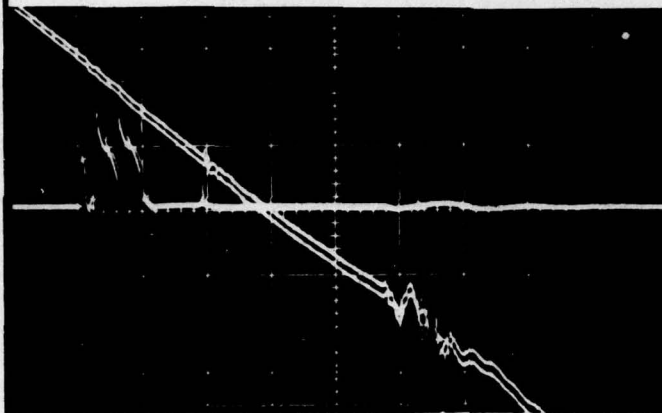
PHASE C

DISTRIBUTION:

TITLE

PREPARED
CORRY 1/24/74
CHECKED
APPROVED

400 HZ BALANCED LOAD
L-T-N VOLTAGES

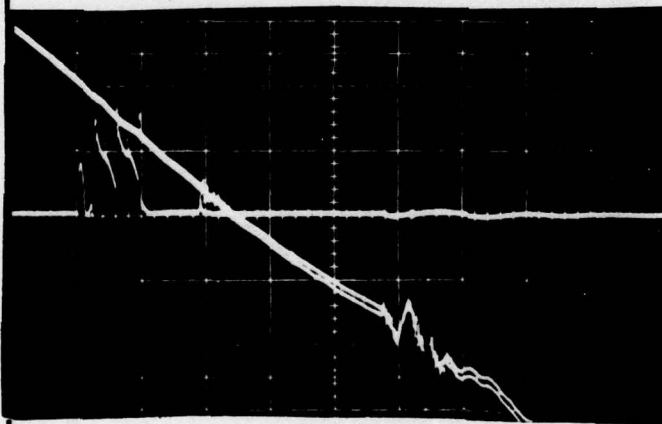


16KW, PF-0.8 LOAD

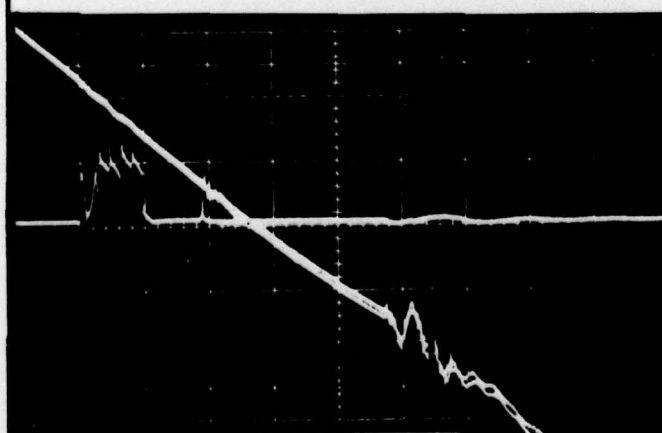
PHASE A

↓ 5V/DIV.

↔ 1.44°/DIV.



PHASE B



PHASE C

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.

0006

PAGE

JOB NO.

THREE PHASE

PAGE

91

TITLE

PREPARED

CORRY

DATE

11/29/74

CHECKED

APPROVED

400 HZ 25 PERCENT UNBALANCED LOAD
AS DESCRIBED IN 3.24.1.5



L-T-N VOLTAGE

PHASE A

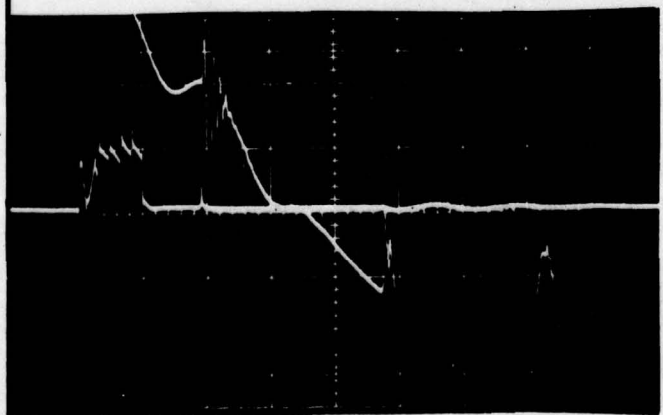
↓ 5V/DIV.

→ 1.44°/DIV.

4.4KW, PF=1.0 LOAD
PHASES A-B



PHASE B



PHASE C

DISTRIBUTION:

DELCO ELECTRONICS GENERAL MOTORS CORPORATION	REPORT NO. ITEM NO. 0006	PAGE	JOB NO. THREE PHASE	PAGE 92
	TITLE		PREPARED CORY	DATE 11/29/79
		CHECKED		
		APPROVED		

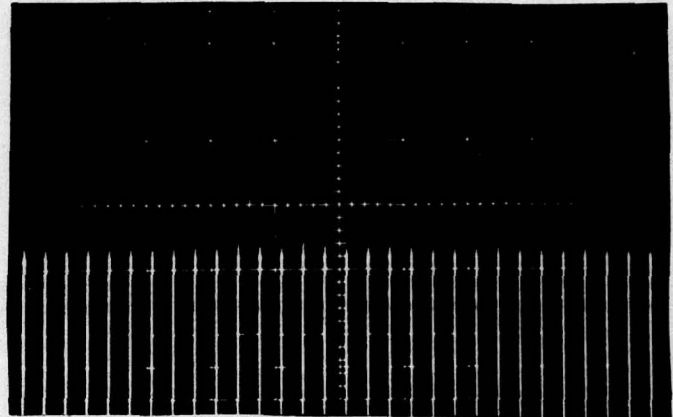
3.24.1.7 VOLTAGE MODULATION

60 HZ THREE PHASE
L-T-N VOLTAGE Van

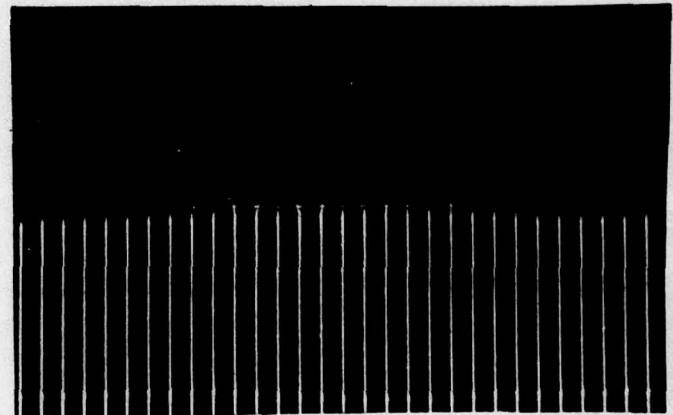
NO LOAD

2V/DIV.

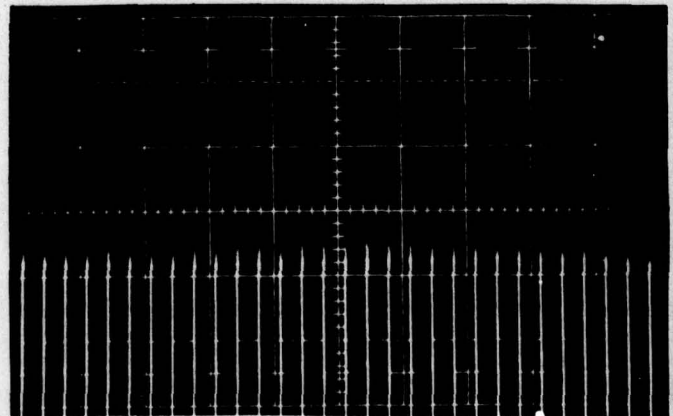
50MS/DIV.



16KW, PF-1.0 LOAD



16KW, PF-0.8 LOAD



DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.

0006

PAGE

JOB NO.

THREE PHASE

PAGE

93

TITLE

PREPARED

CORRY 11/29/74

DATE

CHECKED

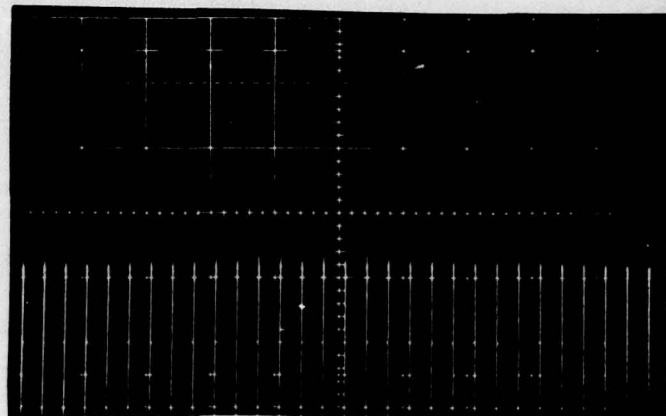
APPROVED

60 HZ THREE PHASE
L-T-L VOLTAGE V_{ab}

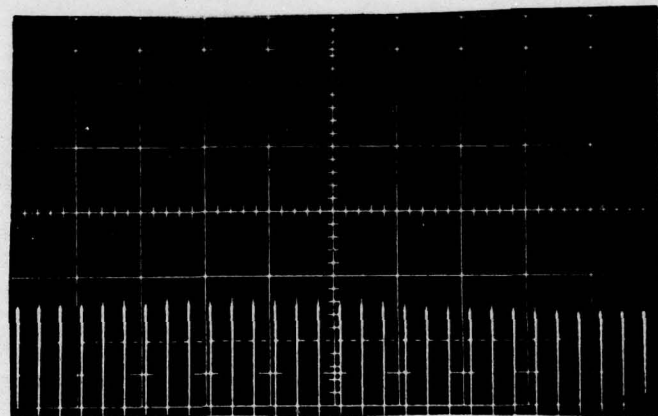
NO LOAD

2V/DIV.

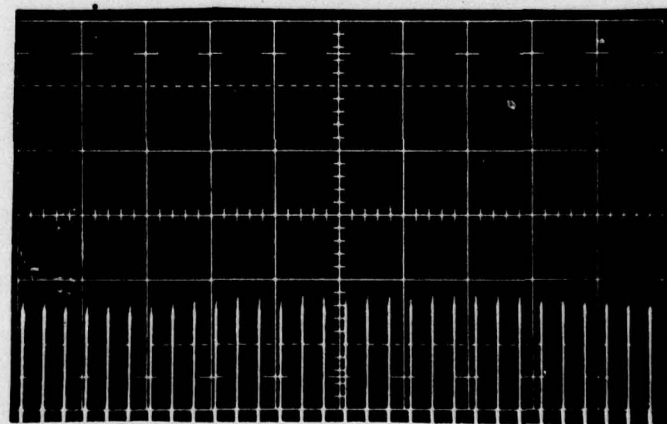
50ms/DIV.



16KW, PF=1.0 LOAD



16KW, PF=0.8 LOAD



DISTRIBUTION:

DELCO ELECTRONICS
GENERAL MOTORS CORPORATION

REPORT NO.
ITEM NO.
0006

PAGE JOB NO.
THREE PHASE

TITLE

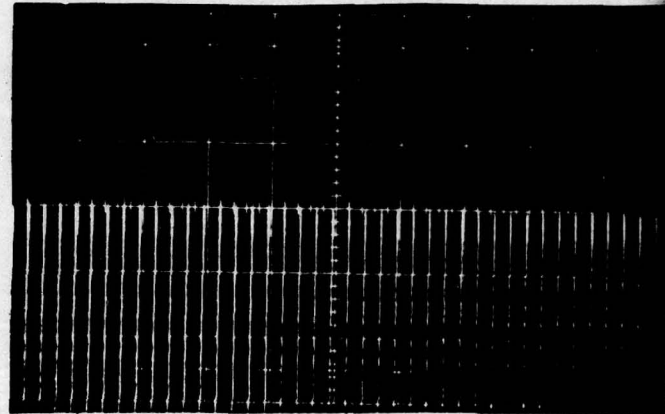
PREPARED
CORRY 11/29/77
CHECKED
APPROVED

400HZ THREE PHASE
L-T-N VOLTAGE Van

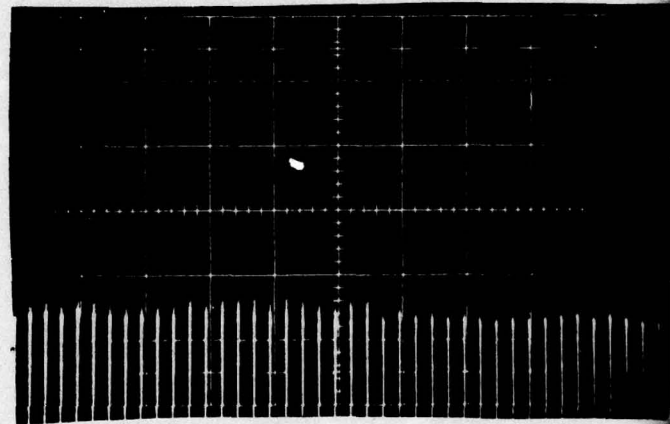
NO LOAD

2V/DIV.

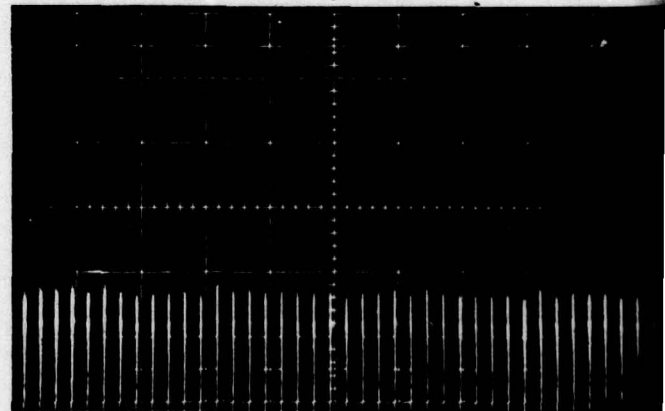
10MS/DIV.



16KW, PF=1.0 LOAD



16KW, PF=0.8 LOAD



DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.

0006

PAGE

JOB NO.

THREE PHASE

PAGE

95

TITLE

PREPARED

CORRY

DATE

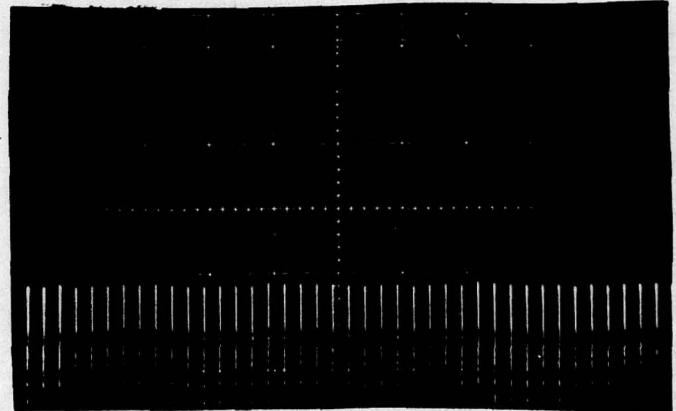
11/29/79

CHECKED

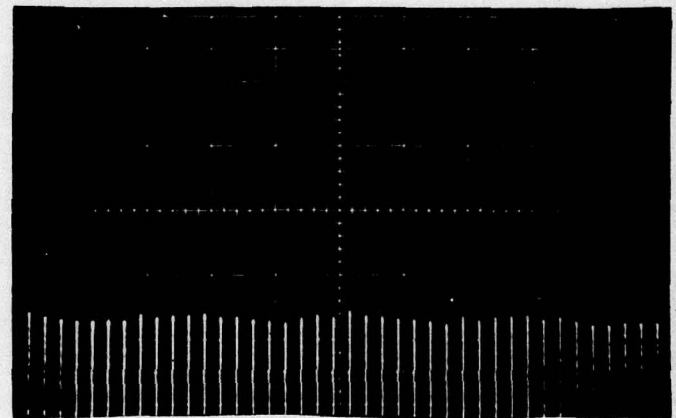
APPROVED

400 HZ, THREE PHASE
L-T-L VOLTAGE V_{ab}

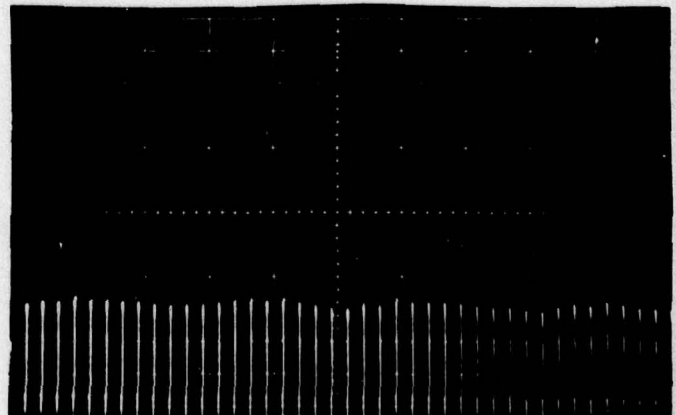
NO LOAD



16KW, PF=1.0 LOAD



16KW, PF=0.8 LOAD

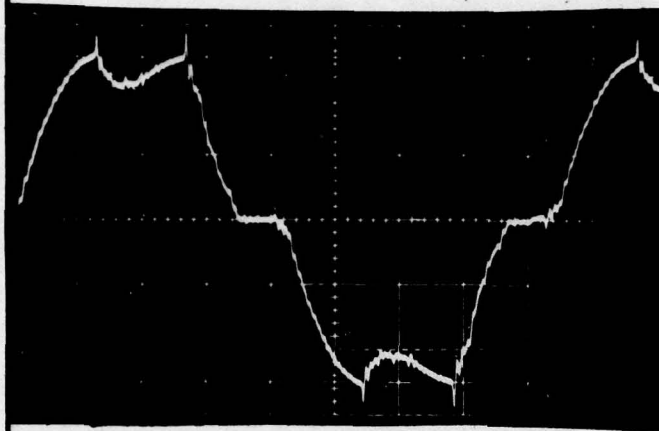


DISTRIBUTION:

DELCO ELECTRONICS GENERAL MOTORS CORPORATION	REPORT NO. ITEM NO. 0006	PAGE	JOB NO. THREE PHASE	PAGE 97
	TITLE		PREPARED CORY 11/29/74	DATE
		CHECKED		
		APPROVED		

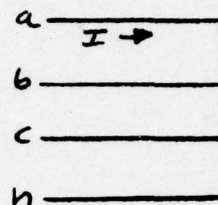
3.29.1.13 SHORT CIRCUIT

60 HZ SHORT CIRCUIT CURRENTS



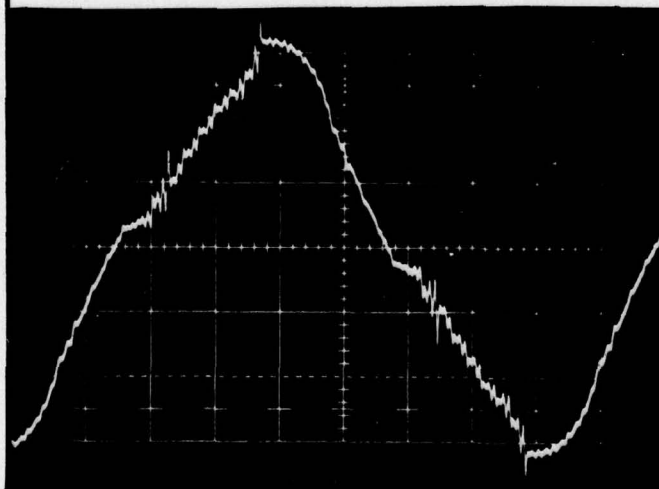
$V_{DC} = 17.5 \text{ VDC}$ (COMM. BOOST
VOLTAGE = 66 VDC, $I_B = 9 \text{ AMPS}$.
FOR ALL 60 HZ SHORT CIRCUIT TESTS)

THREE PHASE SHORT CKT



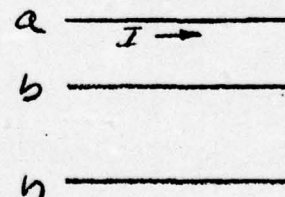
40 A / DIV.
PEAK CURRENT = 100 AMPS*
(2 P.U. PEAK CURRENT RE-
QUIRED) = 116.5 AMPS)

*POWER SOURCE CIRCUIT
BREAKER TRIPS.



$V_{DC} = 22.6 \text{ VDC}$

TWO PHASE SHORT CKT.



40 A / DIV.
PEAK CURRENT = 128 AMPS.

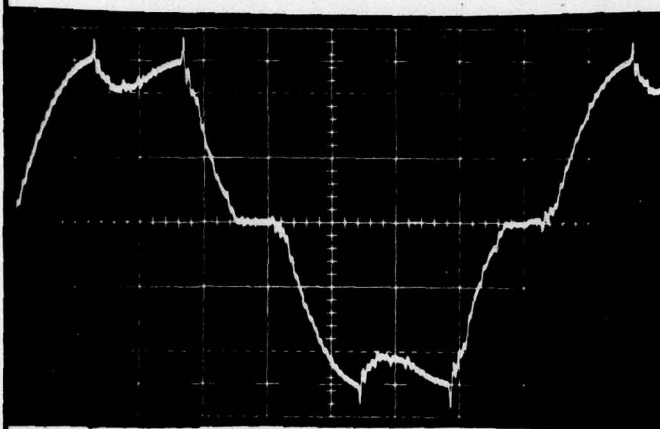
(2 P.U. PEAK CURRENT
REQUIRED) = 116.5 AMPS)

DISTRIBUTION:

DELCO ELECTRONICS GENERAL MOTORS CORPORATION	REPORT NO. ITEM NO. 0006	PAGE	JOB NO. THREE PHASE	PAGE 97
	TITLE		PREPARED CORY	DATE 11/29/74
		CHECKED		
		APPROVED		

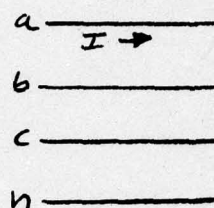
3.24.1.13 SHORT CIRCUIT

60 HZ SHORT CIRCUIT CURRENTS



$V_{DC} = 17.5 \text{ VDC}$ (COMM. BOOST
VOLTAGE = 66 VDC, $I_B = 9 \text{ AMPS}$.
FOR ALL 60 HZ SHORT CIRCUIT TESTS)

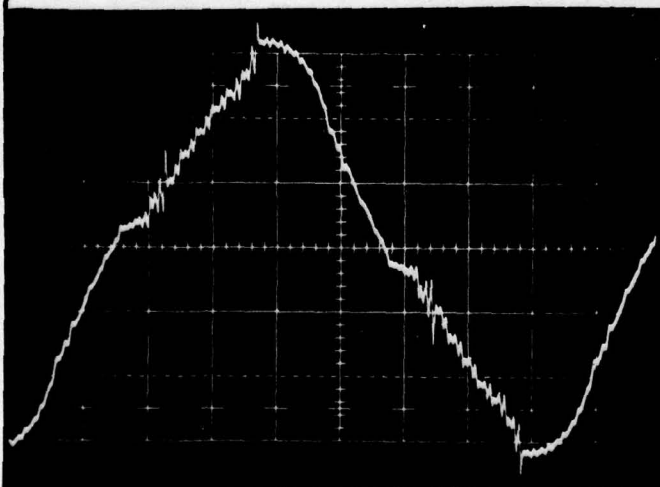
THREE PHASE SHORT CKT



40 A / DIV.

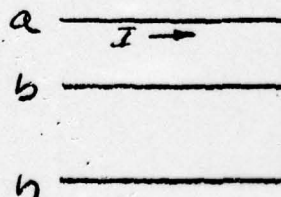
PEAK CURRENT = 100 AMPS*
(2 P.U. PEAK CURRENT RE-
QUIRED) = 116.5 AMPS)

* POWER SOURCE CIRCUIT
BIZKAKER TRIPS.



$V_{DC} = 22.6 \text{ VDC}$

TWO PHASE SHORT CKT.



40 A / DIV.

PEAK CURRENT = 128 AMPS.

(2 P.U. PEAK CURRENT
REQUIRED) = 116.5 AMPS)

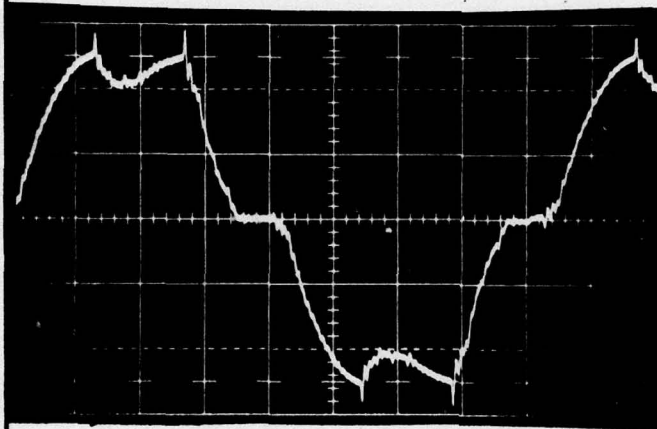
DISTRIBUTION:

TITLE

PREPARED
CORRY 11/29/74
CHECKED
APPROVED

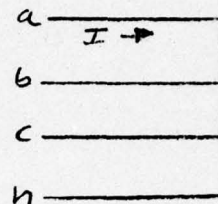
3.24.1.13 SHORT CIRCUIT

60 HZ SHORT CIRCUIT CURRENTS



$V_{DC} = 17.5 \text{ VDC}$ (COMM. BOOST
VOLTAGE = 66 VDC, $I_B = 9 \text{ AMPS}$.
FOR ALL 60 HZ SHORT CIRCUIT TESTS)

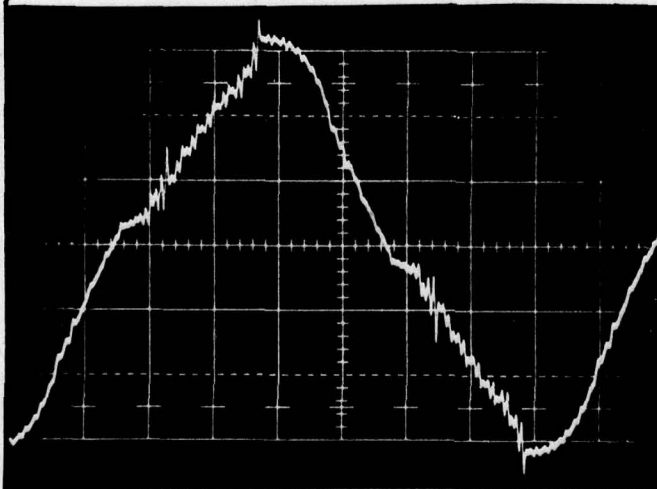
THREE PHASE SHORT CKT



40 A / DIV.

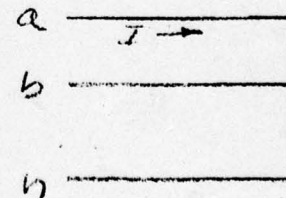
PEAK CURRENT = 100 AMPS*
(2 P.U. PEAK CURRENT RE-
QUICKED = 116.5 AMPS)

* POWER SOURCE CIRCUIT
BIGGER TIPPS.



$V_{DC} = 22.6 \text{ VDC}$

TWO PHASE SHORT CKT.



40 A / DIV.

PEAK CURRENT = 128 AMPS.

(2 P.U. PEAK CURRENT
REQUICKED = 116.5 AMPS)

DISTRIBUTION:

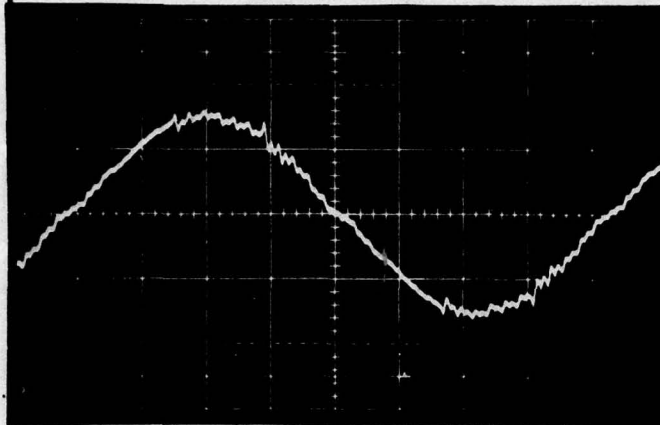
TITLE

PREPARED CORRY DATE 11/29/79

CHECKED

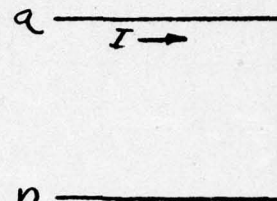
APPROVED

60 HZ SHORT CIRCUIT CURRENTS



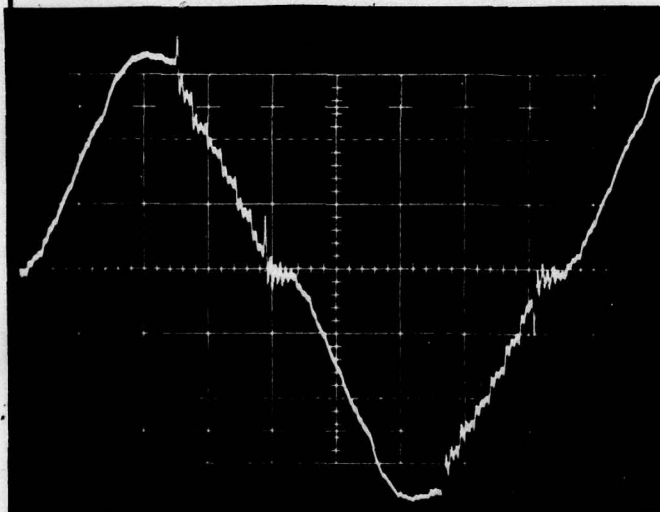
$V_{\alpha} = 50V$

SINGLE PHASE L-T-N
SHORT CIRCUIT



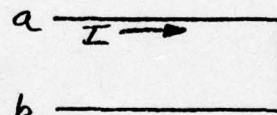
100 A / DIV.

PEAK CURRENT = 150 AMPS.
(2 P.U. PEAK CURRENT RE-
QUIRED) = 116.5 AMPS)



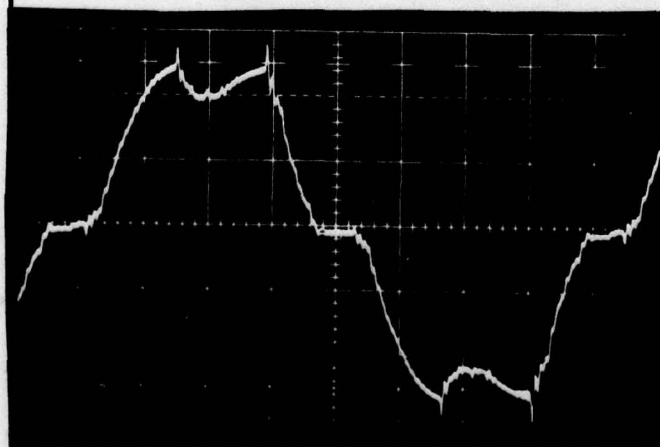
$V_{\alpha} = 23.5V$

SINGLE PHASE L-T-L
SHORT CIRCUIT

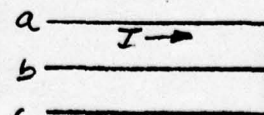


40 A / DIV.

PEAK CURRENT = 150 AMPS
(2 P.U. PEAK CURRENT REQUIRED
FOR 3 ϕ = 116.5 AMPS; FOR
1 ϕ = 146 AMPS)



THREE PHASE L-T-L
SHORT CIRCUIT



40 A / DIV.

PEAK CURRENT = 100 AMPS*
(2 P.U. PEAK CURRENT REQUIRED
= 116.5 AMPS) + POWER SOURCE
BROKE TRIPS.

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.

0006

PAGE

JOB NO.

THREE PHASE

PAGE

99

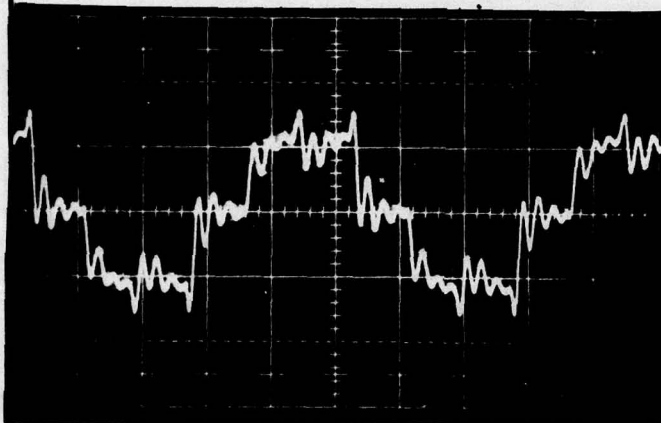
TITLE

PREPARED

CORY 11/29/7

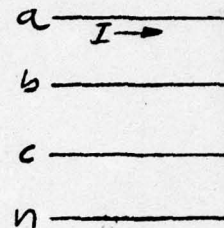
CHECKED

APPROVED

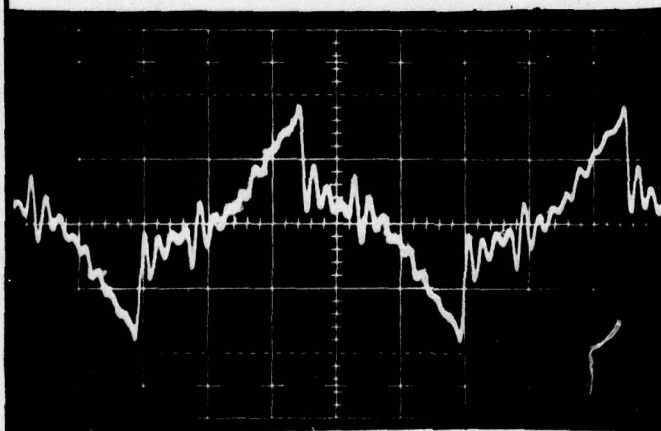
400 HZ SHORT CIRCUIT CURRENTS

$V_{DC} = 18.5V_{DC}$ (COMMUTATION BOOST
VOLTAGE = $72V_{DC}$, $I_B = 6$ AMPS FOR
ALL 400 HZ SHORT CIRCUIT TESTS)

THREE PHASE SHORT CIRCUIT

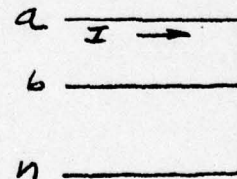


100 A / DIV. 500 μSEC / DIV.
PEAK CURRENT = 120 AMPS.
(2 P.U. PEAK CURRENT RE-
QUIRED) = 116.5 AMPS)



$V_{DC} = 30.9V_{DC}$

TWO PHASE SHORT CIRCUIT



100 A / DIV.

PEAK CURRENT = 180 AMPS.

DISTRIBUTION:

(TESTS CONDUCTED WITH POWER CENTER C.T. COMMUTATION TRANSFORMER SET)

TITLE

PREPARED

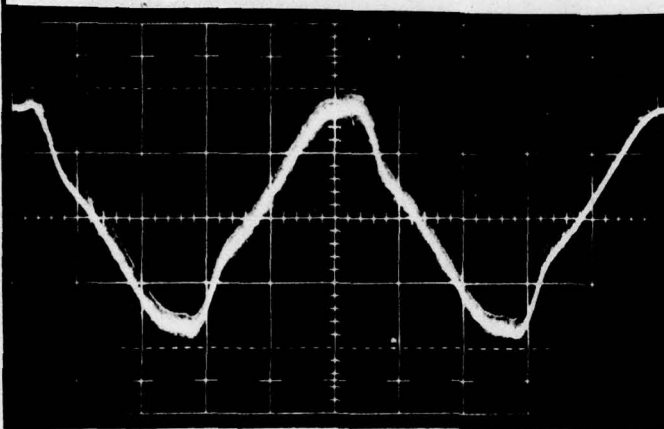
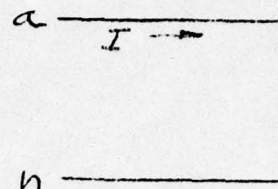
CORY

DATE

11/24/74

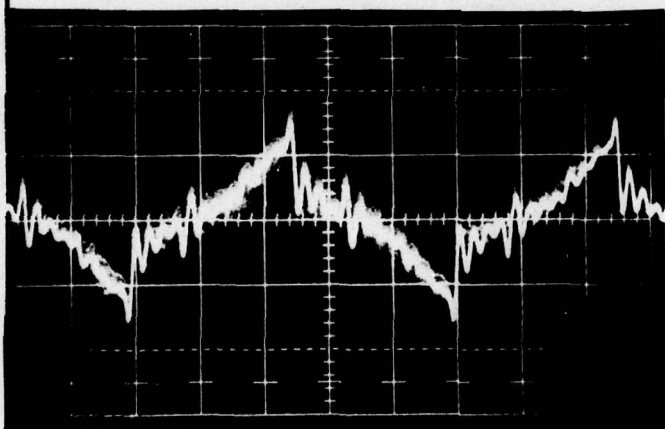
CHECKED

APPROVED

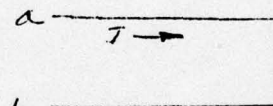
400 HZ SHORT CIRCUIT CURRENTS $V_{DC} = 100V_{DC}$ SINGLE PHASE L-T-N SHORT
CIRCUIT

100A/DIV. 500μSEC/DIV.

PEAK CURRENT = 180 AMPS.

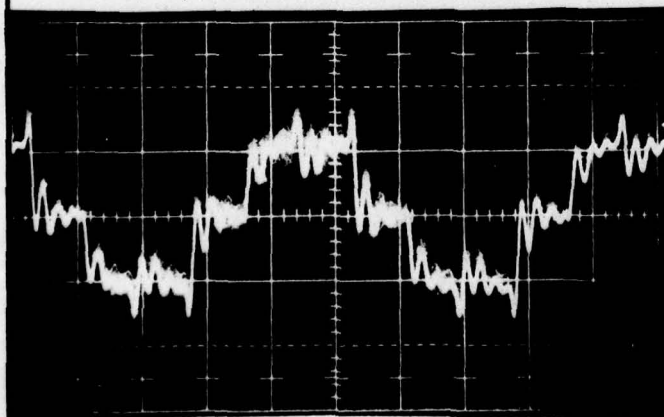
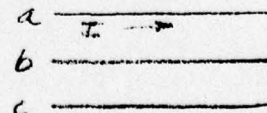
(2 P.U. PEAK CURRENT REQUIRED =
116.5 AMPS) $V_{DC} = 23V_{DC}$

SINGLE PHASE L-T-L SHORT CKT.



100A/DIV. 500μSEC/DIV.

PEAK CURRENT = 150 AMPS

(2 P.U. PEAK CURRENT REQUIRED
FOR 3φ = 116.5 AMPS; FOR 1φ =
146 AMPS) $V_{DC} = 18.5V_{DC}$ THREE PHASE L-T-L
SHORT CIRCUIT

100A/DIV. 500μSEC/DIV.

PEAK CURRENT = 120 AMPS.

(2 P.U. PEAK CURRENT RE-
QUIRED = 116.5 AMPS)

DISTRIBUTION:

DELCO ELECTRONICS GENERAL MOTORS CORPORATION		REPORT NO. ITEM NO. 0006	PAGE	JOB NO. THREE PHASE	PAGE 101
TITLE			PREPARED	CORRY 11/24/74	
			CHECKED		
			APPROVED		

3.24.3 EFFICIENCY* 60HZ

OUTPUT POWER WATTS	P.F.	INPUT POWER WATTS	LOSSES WATTS	EFFICIENCY %
N/O LOAD	—	1445	1445	—
2340	1.0	3435	1095	68.1
2332.8	0.8	3434	1101	67.9
6912	1.0	8047	1135	85.9
6969	0.8	8278	1309	84.2
11,520	1.0	12,725	1205	90.53
11,531	0.8	13,093	1562	88.07
16,628	1.0	18,048	1420	92.13
16,992	0.8	18,916	1924	89.8
21,600	1.0	23,122	1522	93.42
21,888	0.8	24,229	2341	90.33

* INCLUDES COMMUTATION BOOST POWER 720WATTS
DOES NOT INCLUDE POWER TO ELECTRONICS 860WATTS

DISTRIBUTION:

TITLE

PREPARED

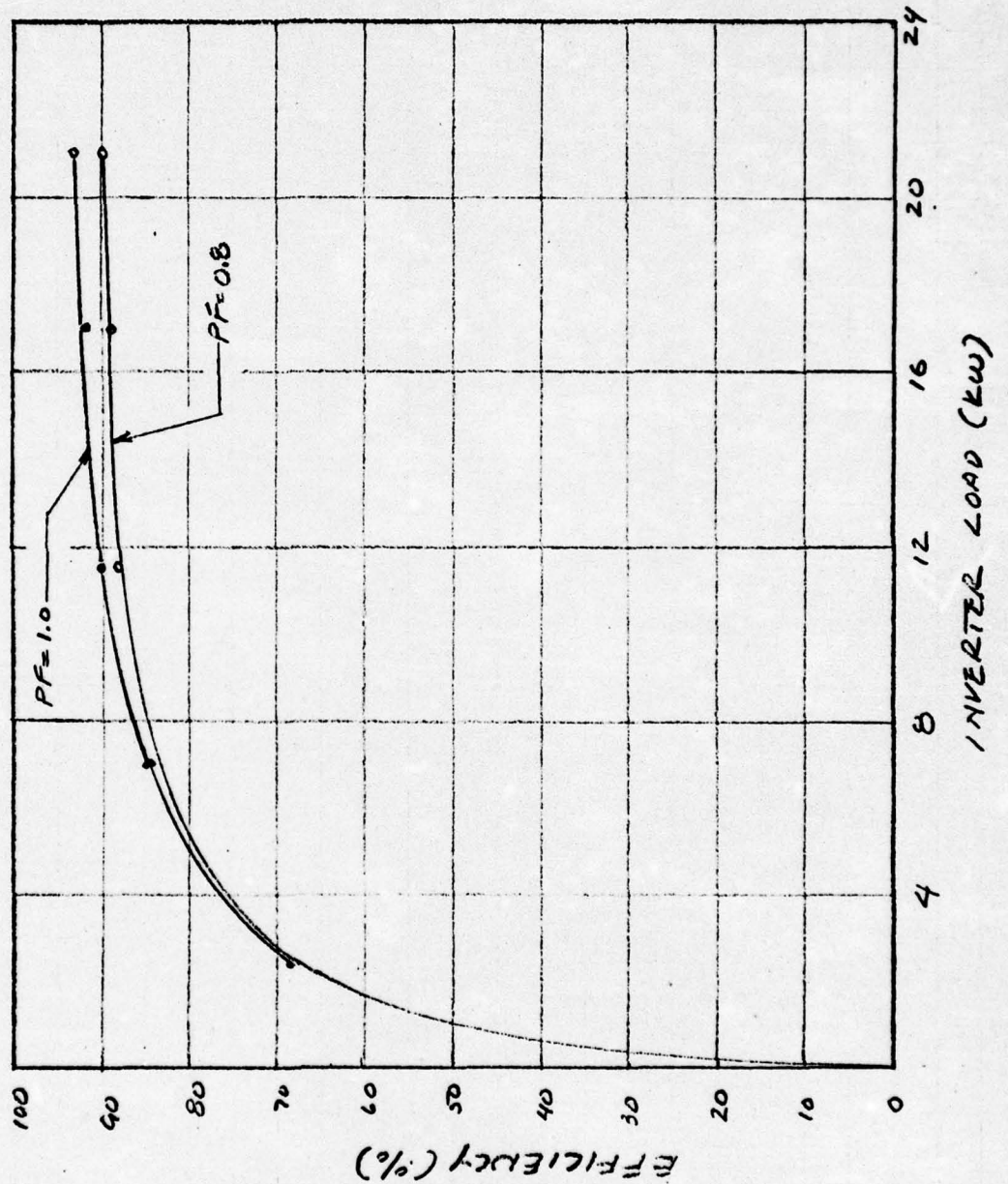
CORRY 11/24/79

DATE

CHECKED

APPROVED

60 HZ EFFICIENCY



DISTRIBUTION:

DELCO ELECTRONICS GENERAL MOTORS CORPORATION	REPORT NO. ITEM NO. 0006	PAGE	JOB NO. THREE PHASE	PAGE 103
	TITLE		PREPARED CORRY	DATE 11/24/79
		CHECKED		
		APPROVED		

3.24.3 EFFICIENCY* 400 HZ

OUTPUT POWER WATTS	P.F.	INPUT POWER WATTS	LOSSES WATTS	EFFICIENCY %
NO LOAD	-	1832	1832	-
2268	1.0	4370	2102	51.9
2304	0.8	4239	1935	54.4
4486	1.0	6516	2030	68.8
4608	0.8	6392	1784	72.1
6732	1.0	8982	2250	75.0
6912	0.8	8791	1829	79.0
9720	1.0	11,300	1580	86.0
9216	0.8	10,926	1710	84.4
11,232	1.0	13,470	2238	83.4
11,462	0.8	13,157	1695	87.1
13,464	1.0	15,893	2429	84.7
13,766	0.8	15,709	1943	87.6
16,560	1.0	19,120	2560	86.6
16,876	0.8	18,784	1908	90.0
20,880	1.0	23,805	2925	87.7
21,600	0.8	23,865	2265	90.5
23,400	1.0	26,162	2762	89.4
23,731	0.8	26,236	2505	90.5

* INCLUDES COMMUTATION BOOST POWER 432 WATTS.
DOES NOT INCLUDE POWER TO ELECTRONICS 260 WATTS.

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.

0006

PAGE

JOB NO.

THREE PHASE

PAGE

104

TITLE

PREPARED

CORRY

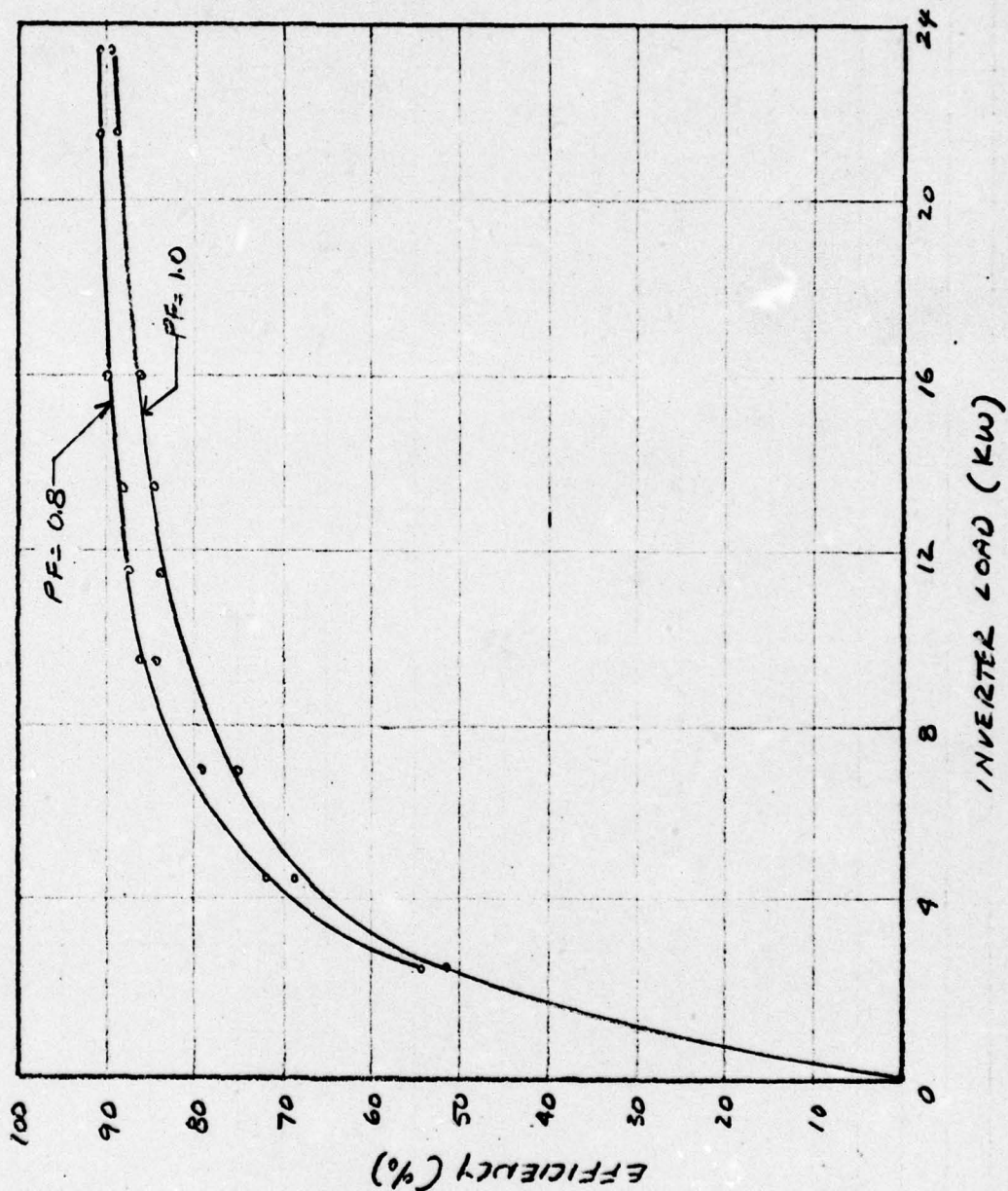
DATE

11/29/79

CHECKED

APPROVED

400HZ EFFICIENCY



DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.

0006

PAGE

JOB NO.

SINGLE PHASE

PAGE

105

TITLE

PREPARED

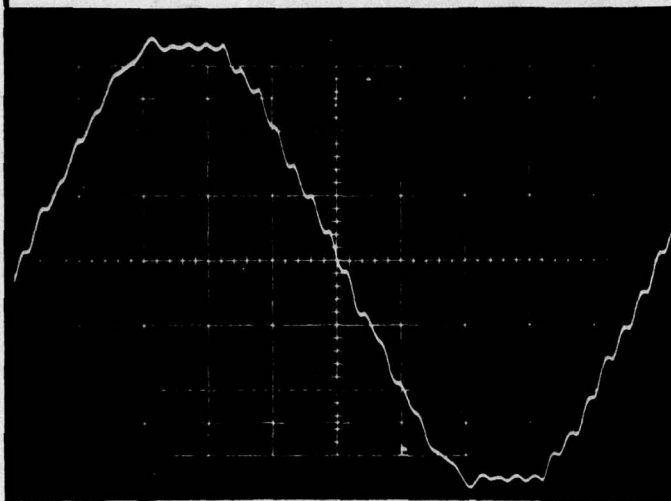
CORY

DATE

12/3/74

CHECKED

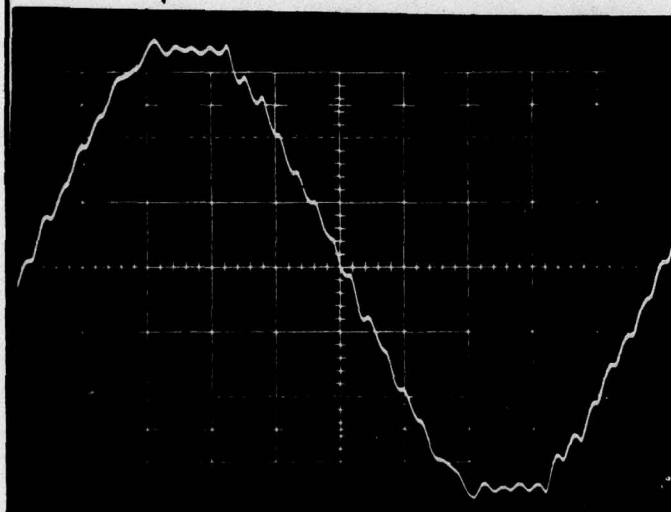
APPROVED

60 HZ SINGLE PHASE
THREE WIRE

NO LOAD

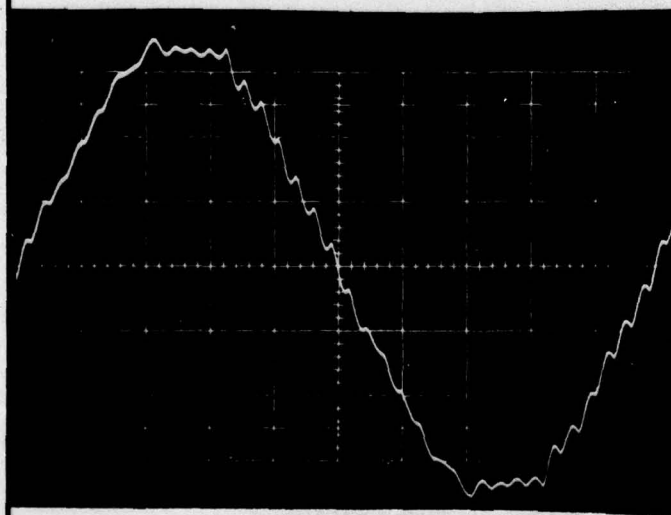
LINE-TO-LINE VOLTAGE
100V/DIV.

THD = 3.65%



10 KW, PF=1.0 LOAD

THD = 3.75%



10 KW, PF=0.8 LOAD

THD = 4.1%

DISTRIBUTION:

TITLE

PREPARED

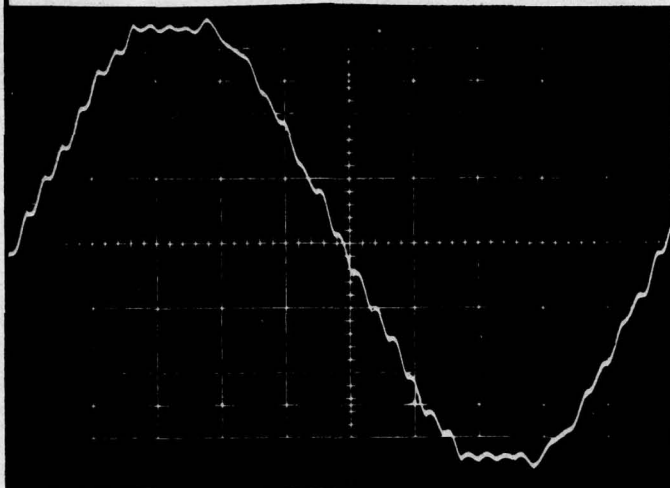
DATE

CORRY 12/3/79

CHECKED

APPROVED

3.24.1.3 VOLTAGE WAVEFORM



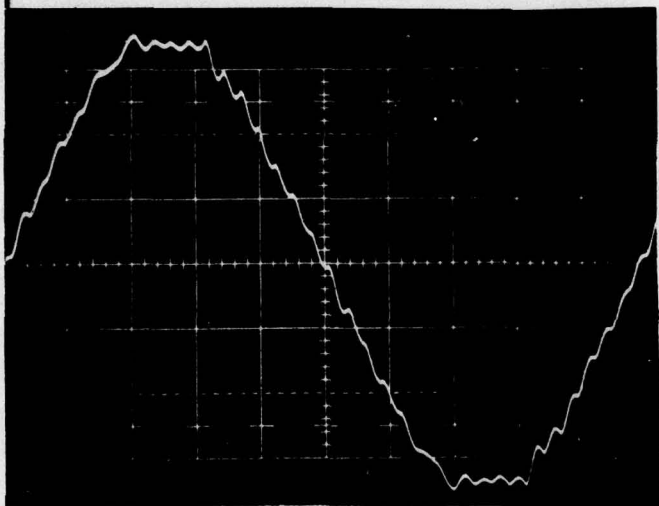
60 HZ SINGLE PHASE
TWO WIRE

NO LOAD

THD = 3.6%

50V/DIV.

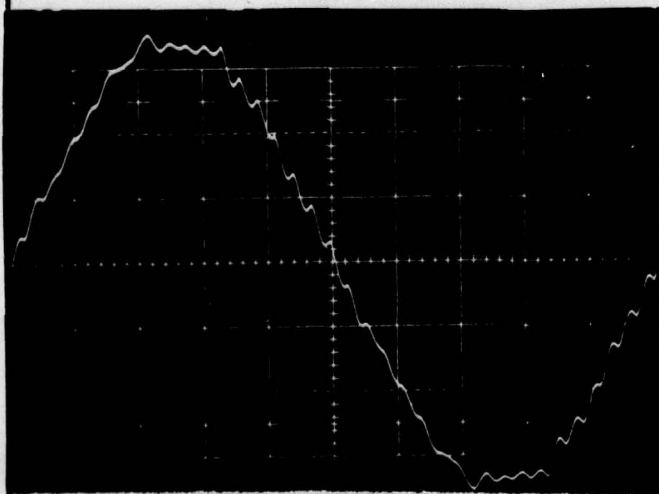
$V_{DC} = 270V_{DC}$



10KW, PF = 1.0 LOAD

THD = 3.75%

$V_{DC} = 275V_{DC}$



10KW, PF = 0.8 LOAD

THD = 4.0%

$V_{DC} = 295V_{DC}$

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

PAGE

JOB NO.

PAGE

SINGLE PHASE

106

TITLE

PREPARED

DATE

CORRY 12/3/74

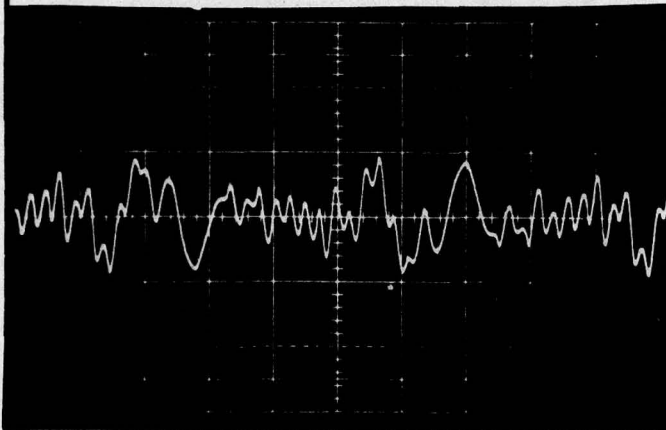
CHECKED

APPROVED

DEVIATION FACTOR

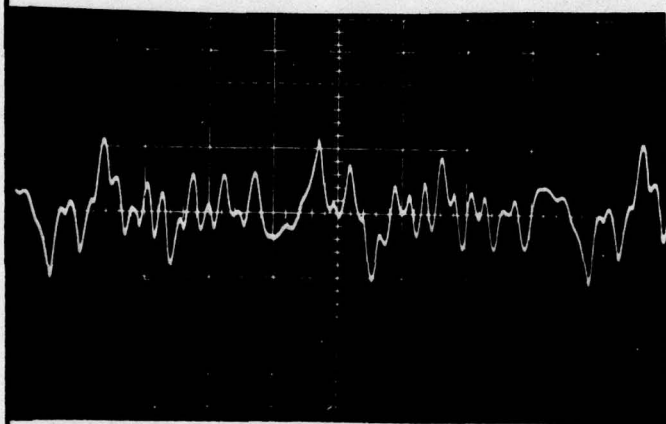
60 HZ SINGLE PHASE

120V RMS

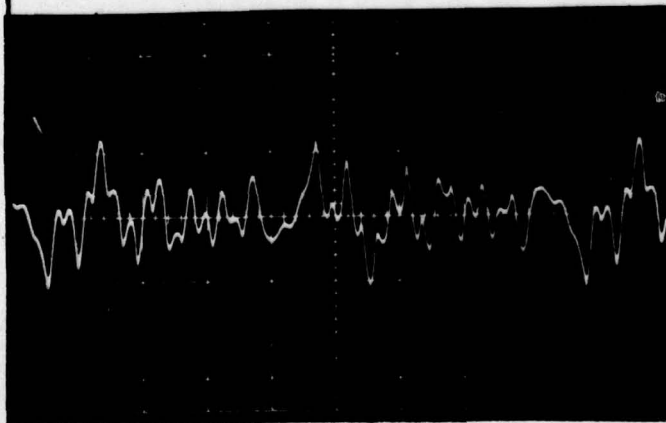


OUTPUT OF 60 HZ NOTCH
FILTER 10V/DIV, 2MS/DIV.

NO LOAD



10 KW, PF = 1.0 LOAD



10 KW, PF = 0.8 LOAD

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

17F-11 NO.

0006

PAGE

JOB NO.

SINGLE PHASE

PAGE

107

TITLE

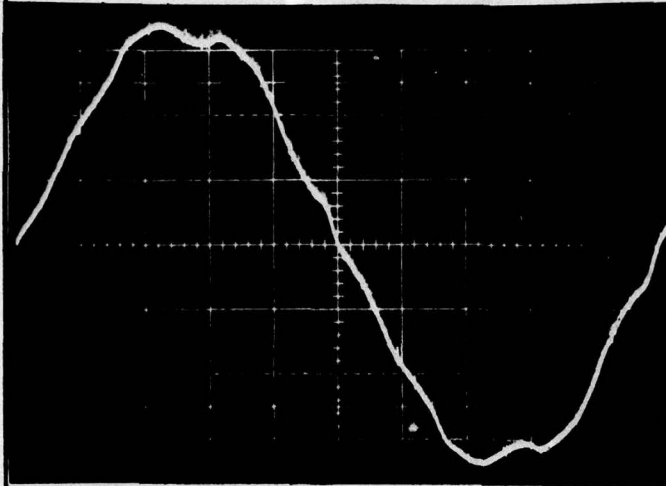
PREPARED

CORY 12/3/79

DATE

CHECKED

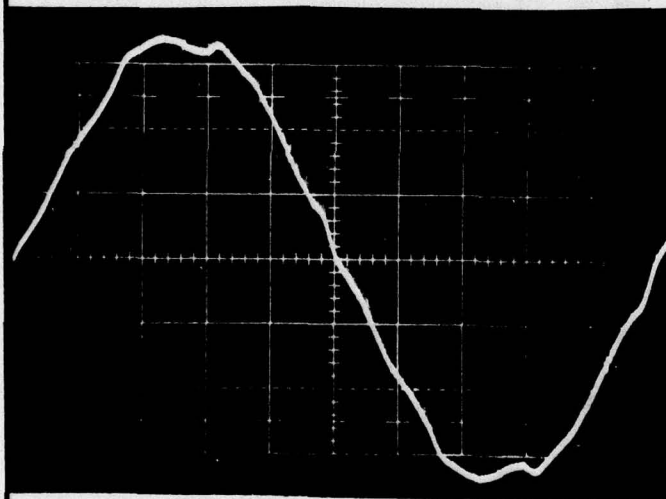
APPROVED

3.24.1.3 VOLTAGE WAVEFORM400 HZ SINGLE PHASE
TWO WIRE

NO LOAD

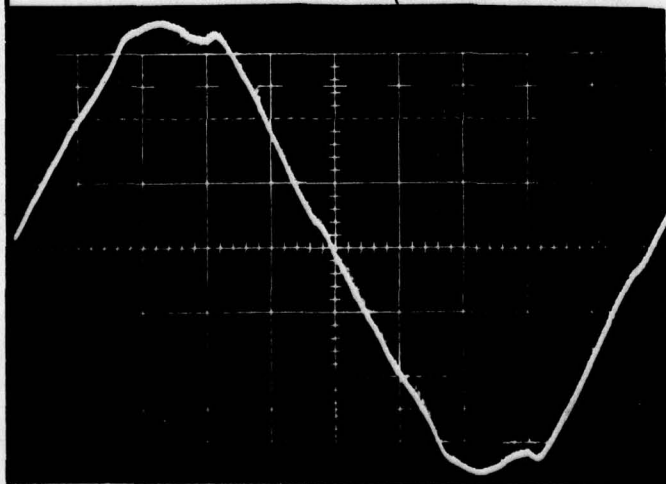
THD = 4.4%

50V / DIV.

 $V_{DC} = 270 \text{ VDC}$ 

10 KW, PF = 1.0 LOAD

THD = 3.2%

 $V_{DC} = 280 \text{ VDC}$ 

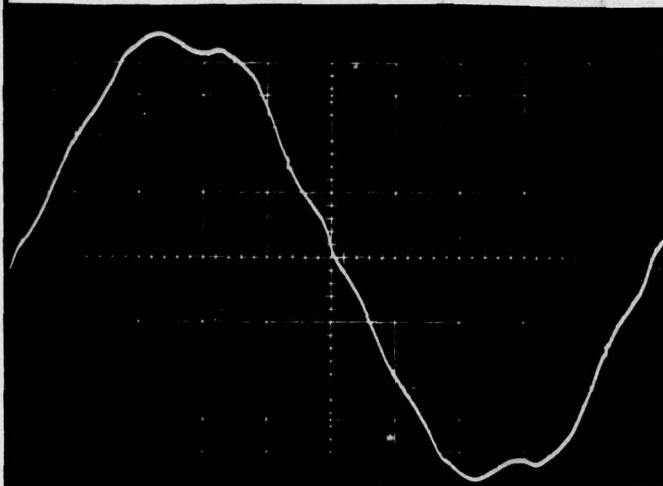
10 KW, PF = 0.8 LOAD

THD = 4.7%

 $V_{DC} = 293 \text{ VDC}$

DISTRIBUTION:

DELCO ELECTRONICS GENERAL MOTORS CORPORATION	REPORT NO. ITEM NO. 0006	PAGE	JOB NO. SINGLE PHASE	PAGE 108
	TITLE		PREPARED CORY	DATE 12/3/79
		CHECKED		
		APPROVED		

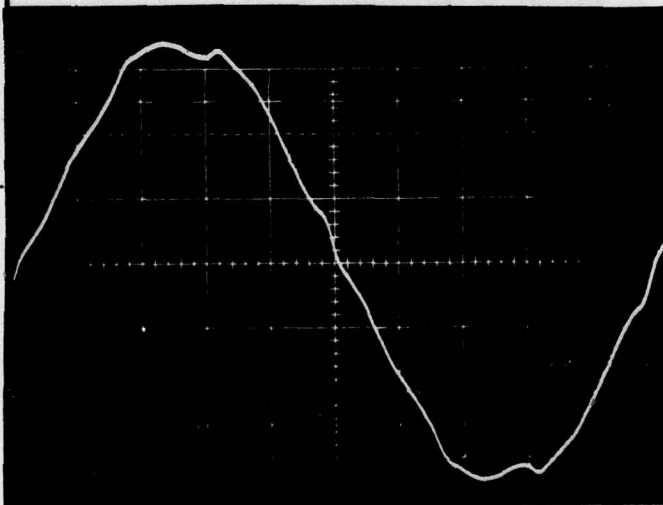


400 HZ SINGLE PHASE
THREE WIRE

NO LOAD

THD = 4.4%

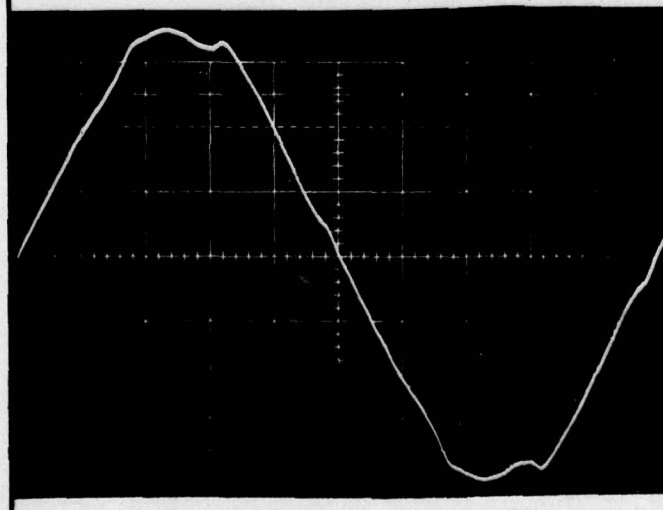
$V_{DC} = 273V_{DC}$



10 KW, PF = 1.0 LOAD

THD = 3.4%

$V_{DC} = 287V_{DC}$



10 KW, PF = 0.8 LOAD

THD = 3.9%

$V_{DC} = 298V_{DC}$

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.

0006

PAGE

JOB NO.

SINGLE PHASE

PAGE

109

TITLE

PREPARED

CORRY

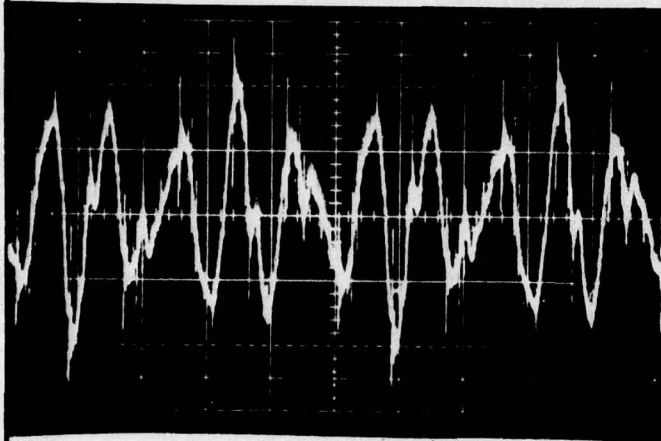
DATE

12/3/79

CHECKED

APPROVED

DEVIATION FACTOR

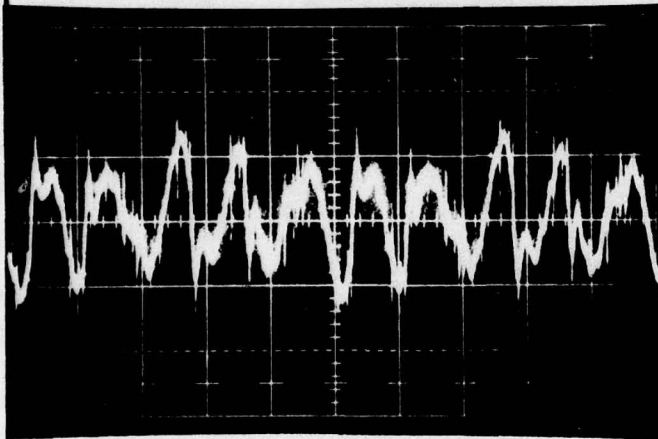


400 HZ SINGLE PHASE
TWO WIRE

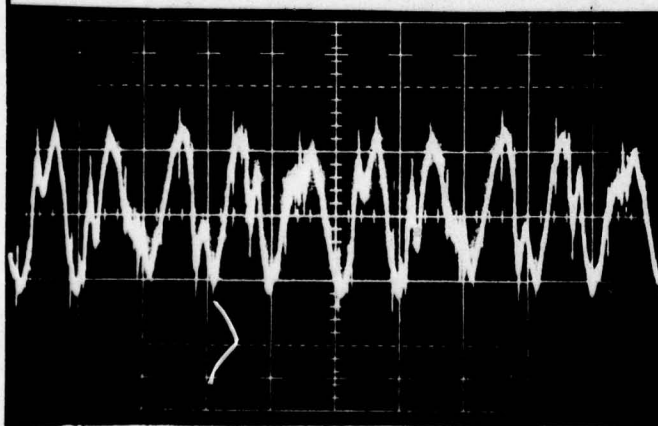
NO LOAD

0.5V/DIV.

500 μSEC/DIV.



10KW, PF=0.8 LOAD



10KW, PF=1.0 LOAD

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.

0006

PAGE

JOB NO.

SINGLE PHASE

PAGE

111

TITLE

PREPARED

CORRY

DATE

12/3/74

CHECKED

APPROVED

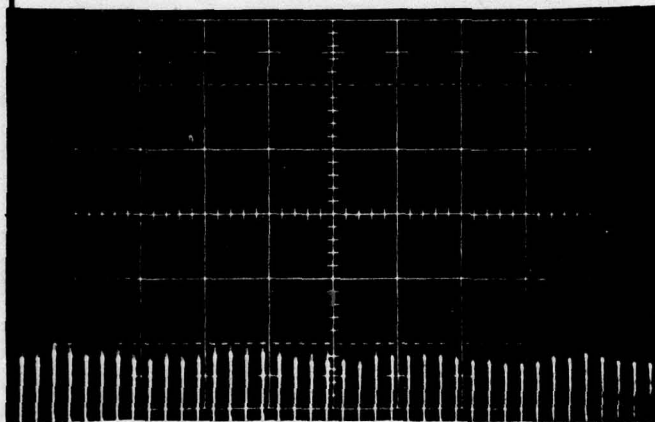
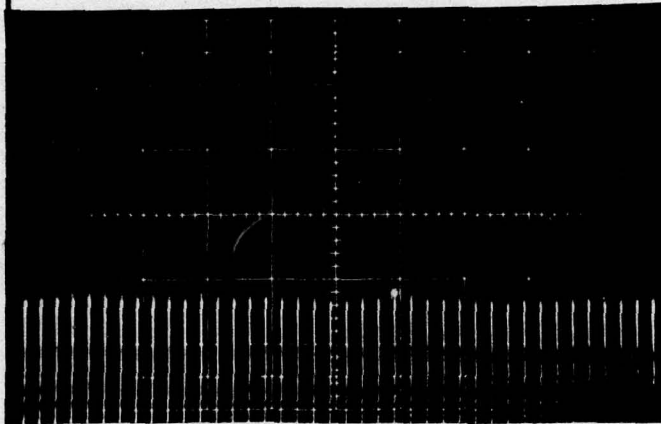
VOLTAGE MODULATION

400 HZ SINGLE PHASE
TWO WIRE

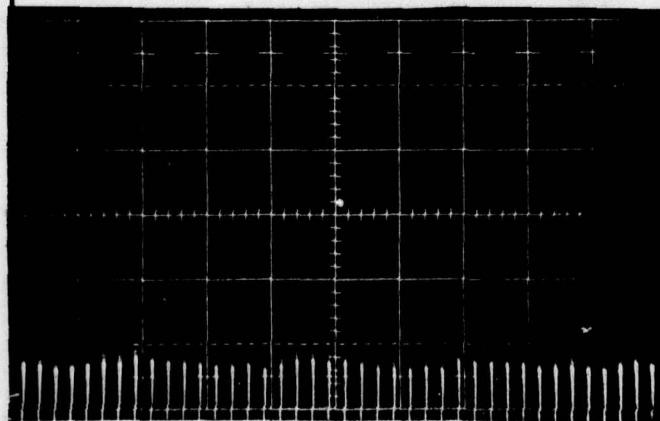
NO LOAD

2V/DIV.

10MS/DIV.



10KW, PF=1.0

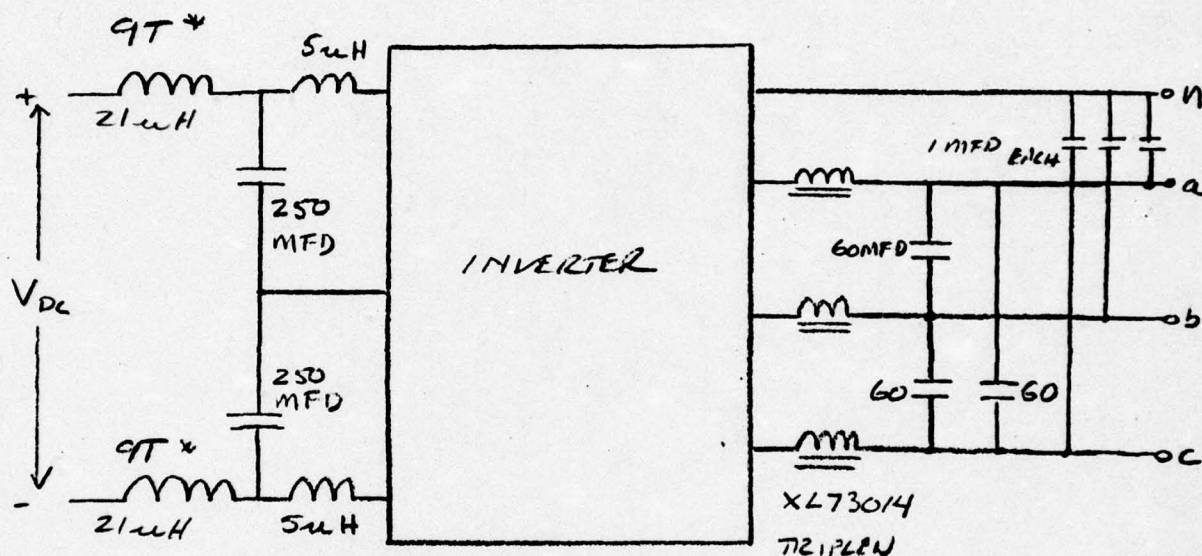


10KW, PF=0.8

DISTRIBUTION:

DELCO ELECTRONICS GENERAL MOTORS CORPORATION	REPORT NO. ITEM NO. C0006	PAGE	JOB NO. DESIGN DATA	PAGE 112
	TITLE		PREPARED CORY 12/9/79	DATE
		CHECKED		
		APPROVED		

EXPERIMENT TO STUDY THE INFLUENCE OF
THE INVERTER INPUT FILTER ON THE OUTPUT
WAVEFORM. 400 HZ, THREE PHASE



* @ 55-55106-D4 CORE

($V_{BOOST} = 72VDC$; $I_B = 6AMPS$. C.T. COMMUTATION
TRANSFORMER USED FOR FULLER CENTER COMMUTATION)

(NOTE: TWO WIRE INPUT COMPARED TO THREE
WIRE INPUT FOR DATA ON PAGES 73-76)

DISTRIBUTION:

DELCO ELECTRONICS GENERAL MOTORS CORPORATION	REPORT NO. ITEM NO. 0006	PAGE 113	JOB NO. DESIGN DATA	PAGE 113
	TITLE RESULTS OF INPUT FILTER EXPERIMENT		PREPARED CORRY	DATE 12/19/74
		CHECKED		
		APPROVED		

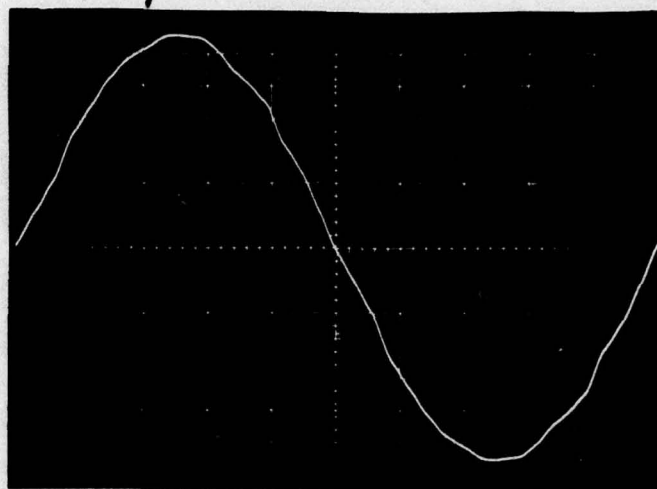
3.24.13 VOLTAGE WAVEFORM
 400HZ, THREE PHASE
NO LOAD

L-T-N VOLTAGES

V_{an}

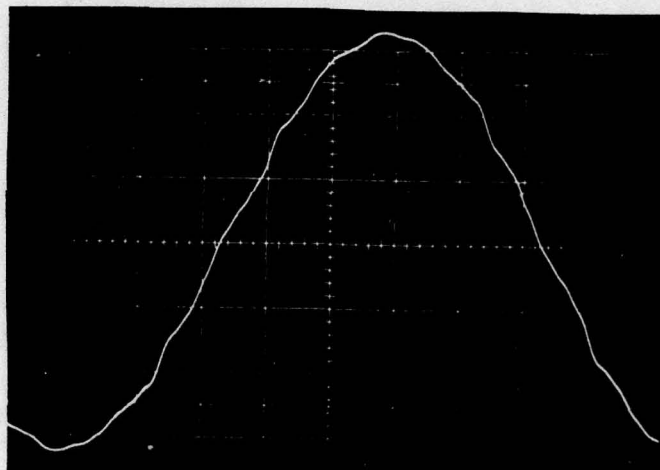
THD = 2.0%

50V/DIV.



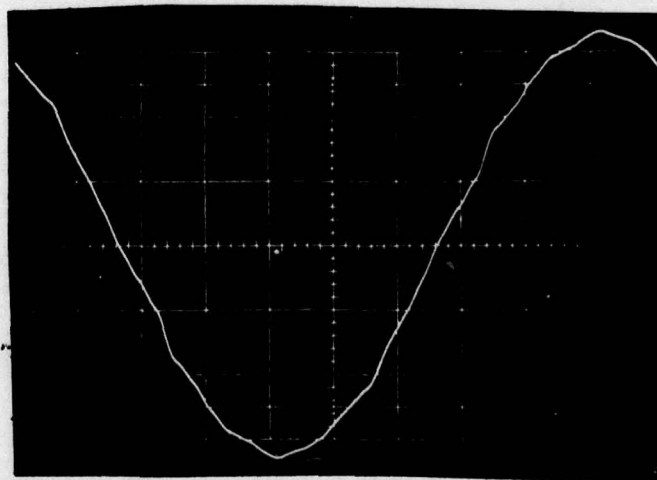
V_{bn}

THD = 2.5%



V_{cn}

THD = 2.2%



COMPARE WITH PAGE 73

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.
ITEM NO.
0006

PAGE JOB NO.
DESIGN
DATA

PAGE
114

TITLE

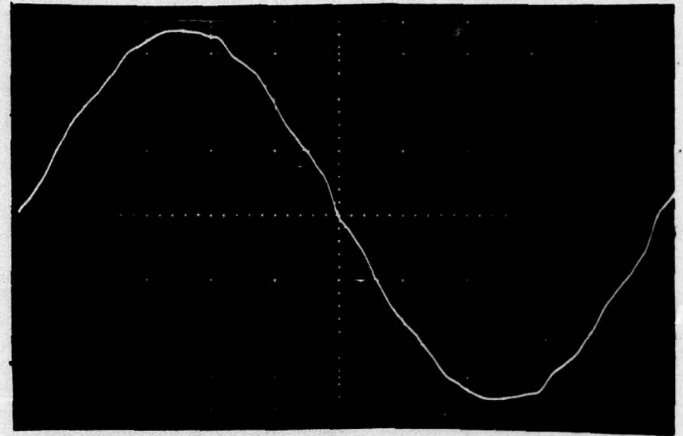
PREPARED
CORRY 12/9/79
DATE
CHECKED
APPROVED

400 HZ, THREE PHASE
LINE-TO-LINE VOLTAGES

NO LOAD
 V_{ab}

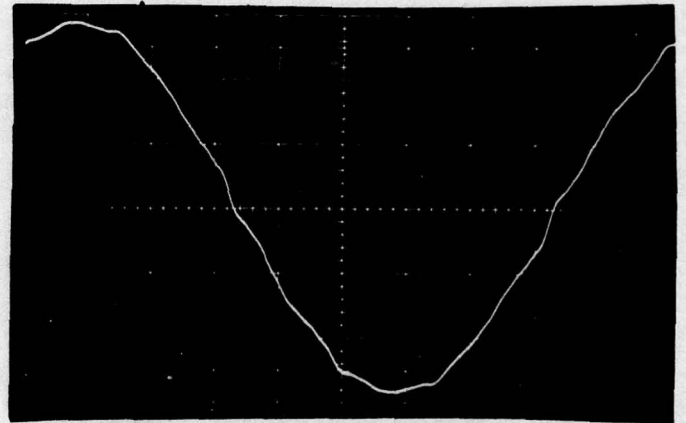
THD = 2.1%

100V/DIV.



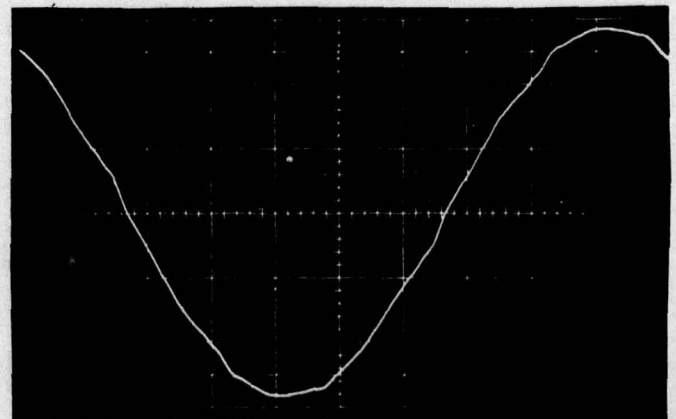
V_{bc}

THD = 2.4%



V_{ca}

THD = 2.1%



COMPARE WITH PAGE 74

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.
0006

PAGE

JOB NO.

DESIGN
DATA

PAGE

115

TITLE

PREPARED

CORRY 12/9/79

DATE

CHECKED

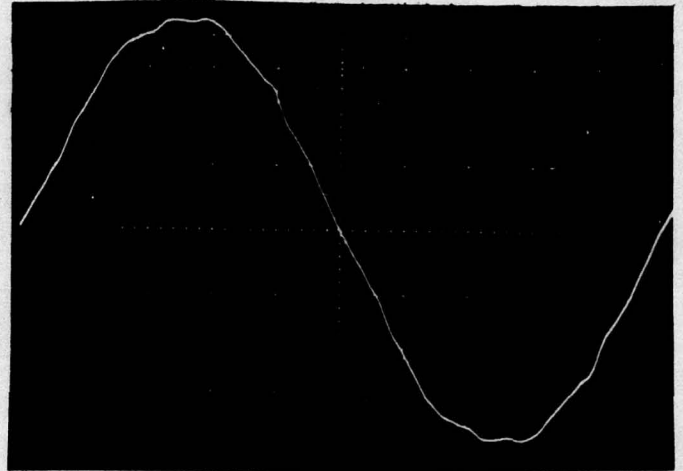
APPROVED

400 HZ, THREE PHASE
LINE-TO-NEUTRAL VOLTAGES

11KW, PF=1.0 LOAD

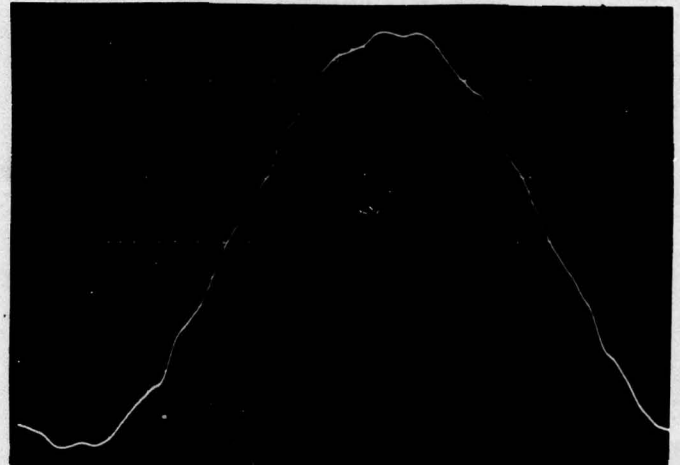
V_{an}

THD=2.5%



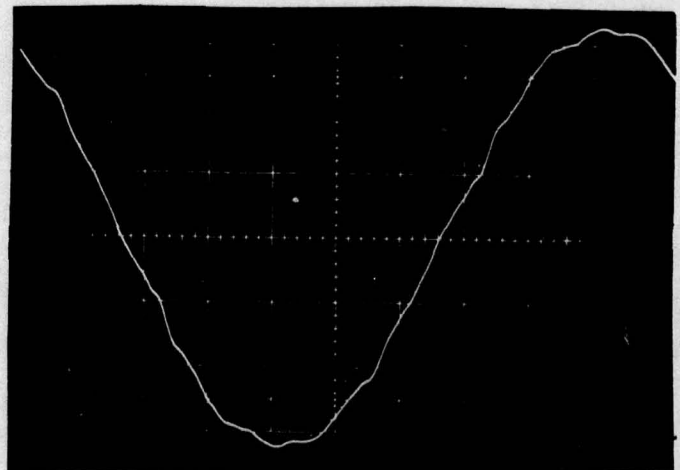
V_{bn}

THD=2.95%



V_{cn}

THD=2.55%



DISTRIBUTION:

TITLE

PREPARED
CORRY
DATE
12/9/74
CHECKED
APPROVED

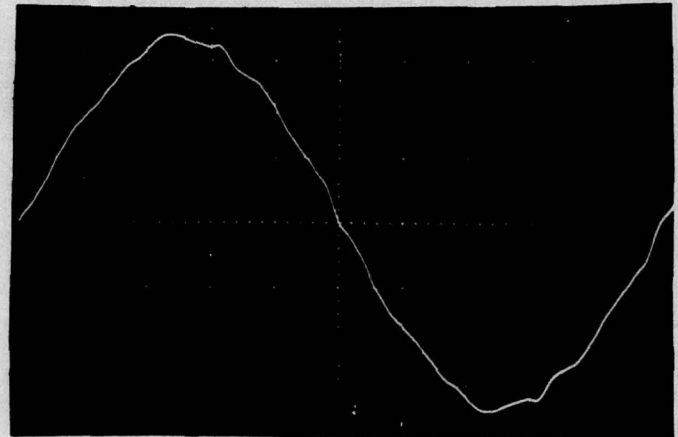
400 HZ, THREE PHASE
LINE-TO-LINE VOLTAGES

11KW, PF=1.0 LOAD

V_{ab}

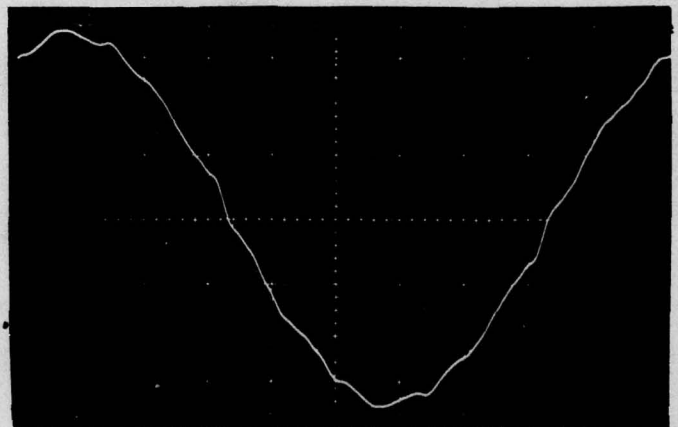
THD= 2.5%

100V/DIV.



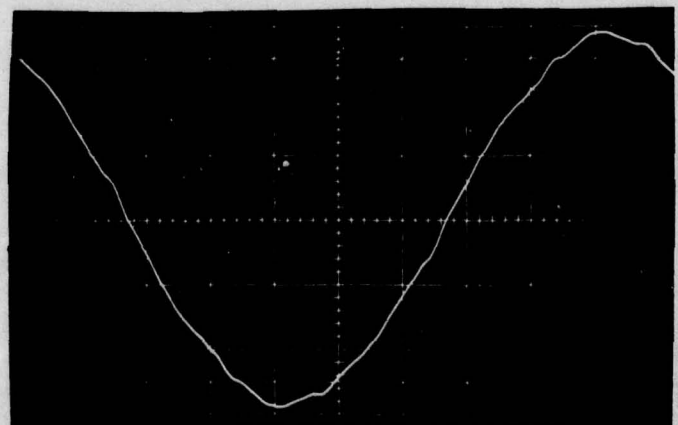
V_{bc}

THD= 2.9%



V_{ca}

THD= 2.55%



DISTRIBUTION:

TITLE

PREPARED

CORRY 12/9/79

DATE

CHECKED

APPROVED

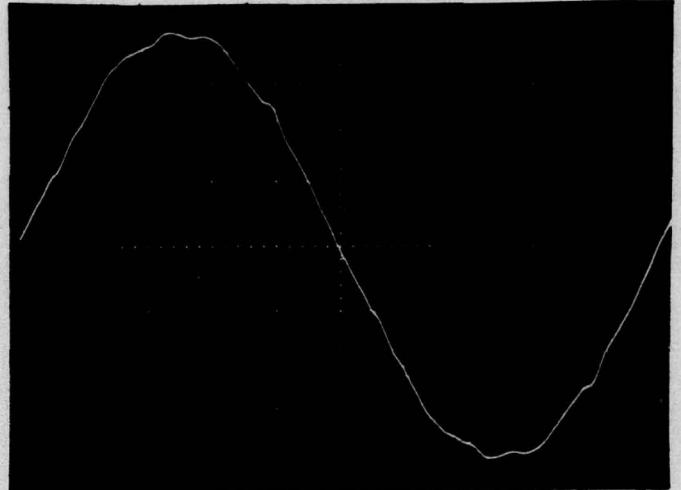
400 HZ, THREE PHASE
LINE-TO-NEUTRAL VOLTAGES

11KW, PF=0.8 LOAD

V_{an}

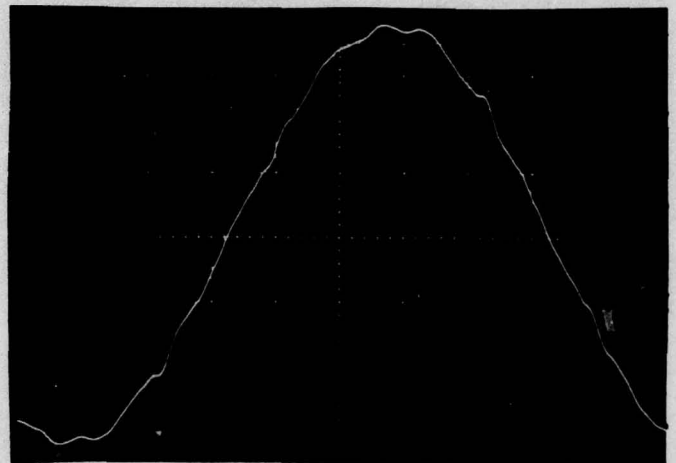
THD= 2.2%

50V/DIV.



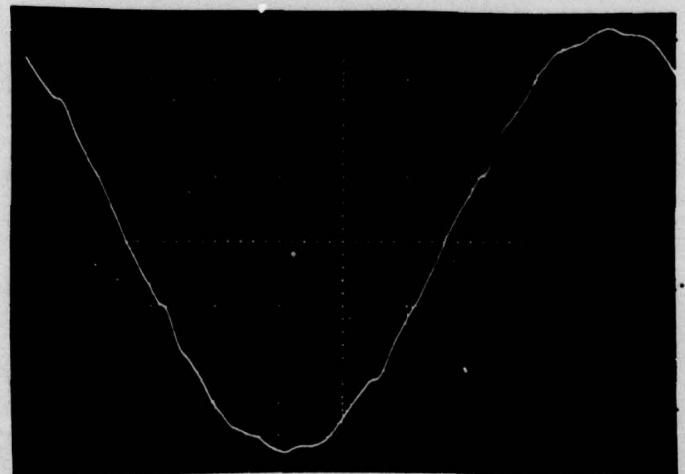
V_{bn}

THD= 2.6%



V_{cn}

THD= 2.3%



COMPARE WITH PAGE 119

DISTRIBUTION:

TITLE

PREPARED
CORR-1
DATE
12/9/79

CHECKED

APPROVED

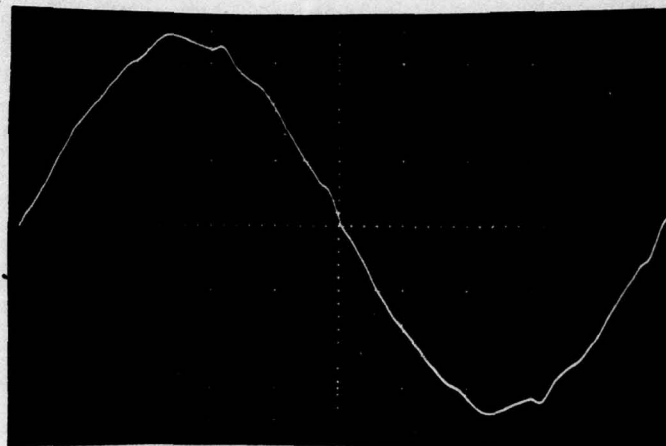
400 HZ, THREE PHASE
LINE-TO-LINE VOLTAGE

11KW, PF=0.8 LOAD

V_{ab}

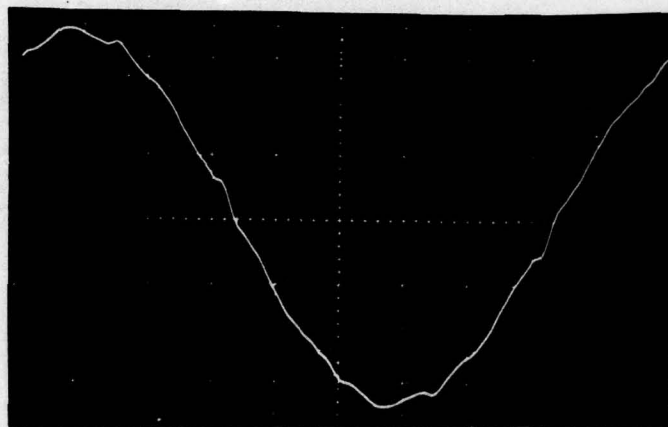
THD=2.2%

100V/DIV.



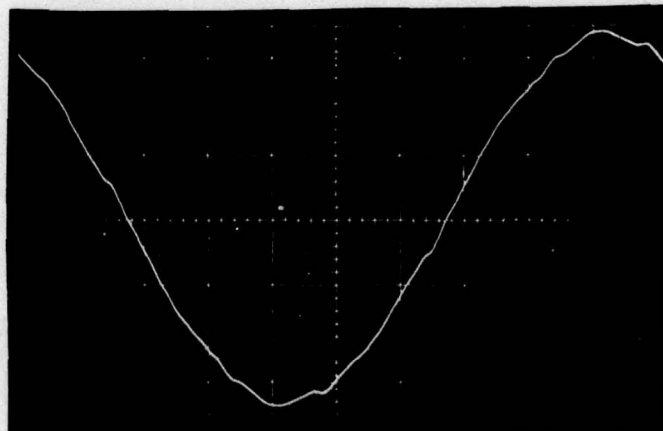
V_{bc}

THD=2.6%



V_{ca}

THD=2.3%



DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.

0006

PAGE

JOB NO.

DESIGN

DATA

PAGE

119

TITLE

V_{BOOST} REDUCED TO 20 VOLTS; $I_B = 2$ AMPS
FOR THIS TEST.

PREPARED

CORRY

DATE

12/9/74

CHECKED

APPROVED

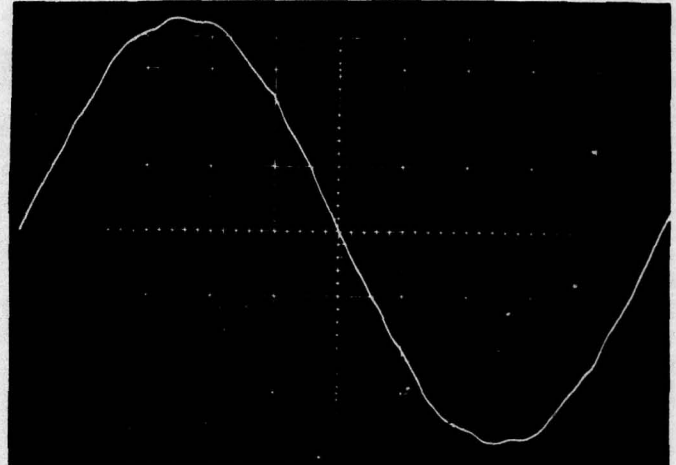
400HZ, THREE PHASE
LINE-TO-NEUTRAL VOLTAGES

11KW, PF=0.8 LOAD

V_{an}

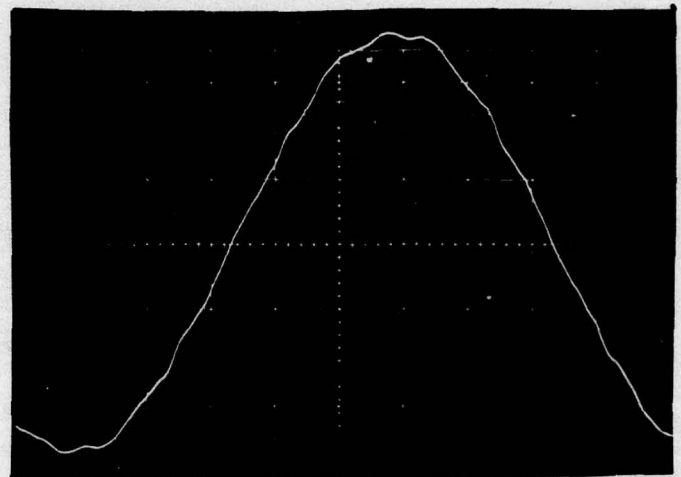
THD= 1.7%

50V/DIV.



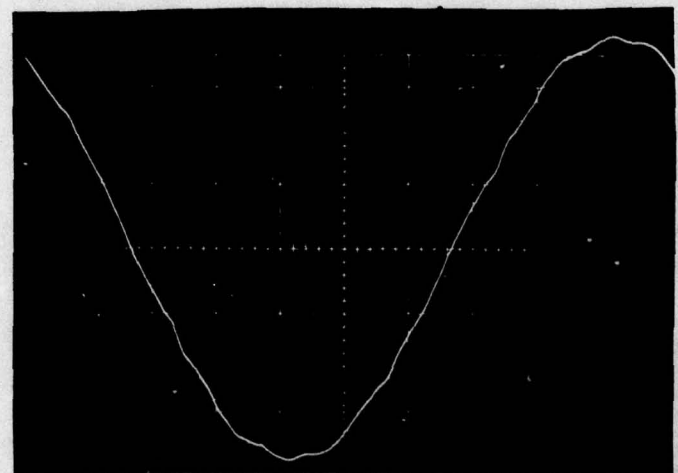
V_{bn}

THD= 2%



V_{cn}

THD= 1.9%



COMPARE WITH PAGE 117

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.

0006

PAGE

JOB NO.

DESIGN

DATA

PAGE

120

TITLE

PREPARED

CORRY

DATE

12/9/74

CHECKED

APPROVED

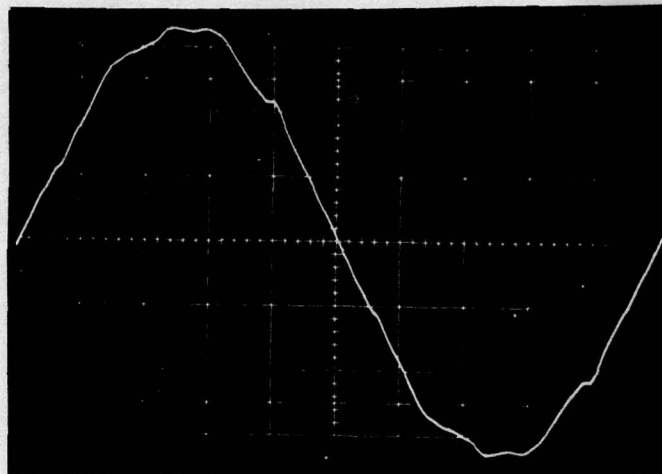
400 HZ, THREE PHASE
LINE-TO-NEUTRAL VOLTAGES

16LW, PF=0.8 LOAD

V_{an}

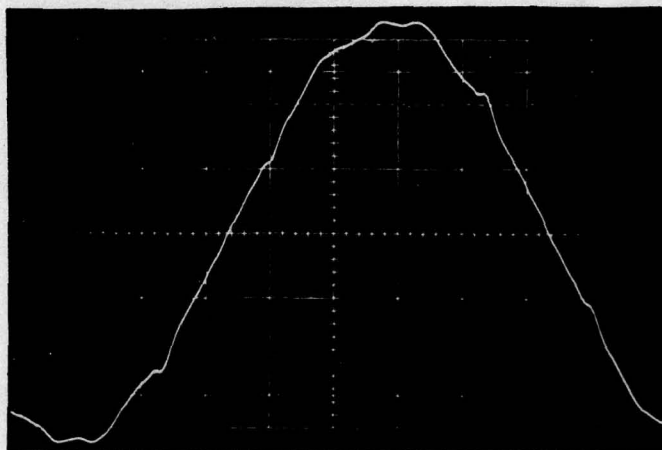
THD= 2.8%

50V/DIV.



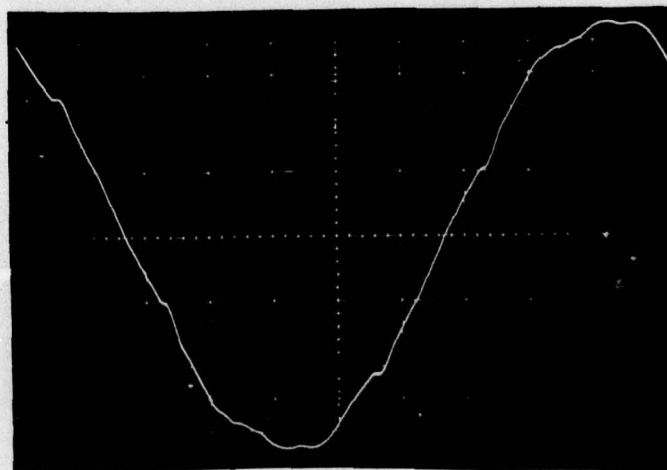
V_{bn}

THD= 3.1%



V_{cn}

THD= 3.1%



COMPARE WITH PAGE 75

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.

0006

PAGE

JOB NO.

DESIGN

DATA

PAGE

121

TITLE

PREPARED

CORR-1

DATE

12/9/79

CHECKED

APPROVED

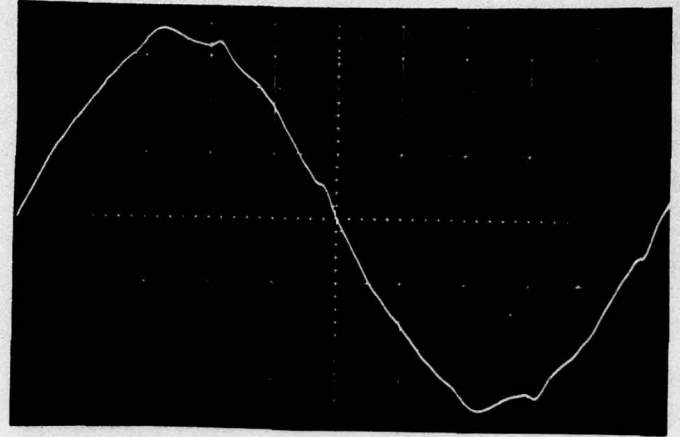
400 HZ, THREE PHASE
LINE-TO-LINE VOLTAGES

16KW, PF=0.8 LOAD

V_{ab}

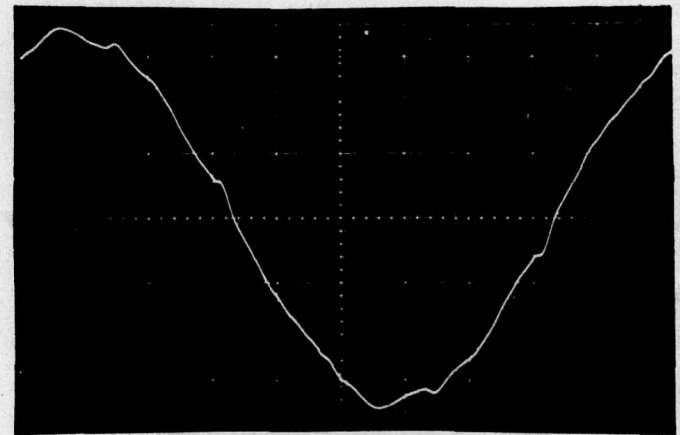
THD= 2.8%

100V/DIV.



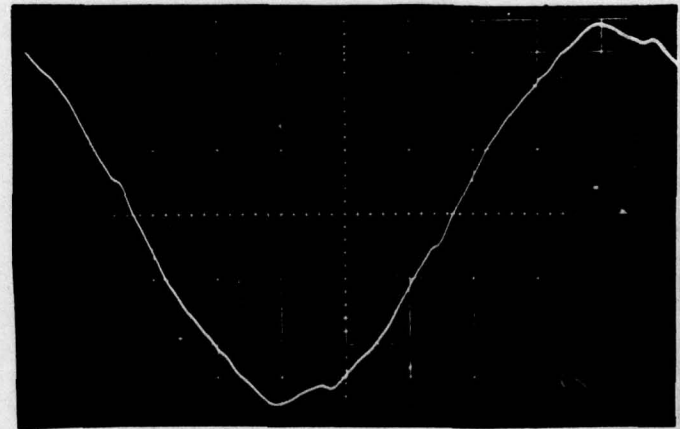
V_{bc}

THD= 3.1%



V_{cn}

THD= 3.1%



COMPARE WITH PAGE 76

DISTRIBUTION:

DELCO ELECTRONICS GENERAL MOTORS CORPORATION	REPORT NO. ITEM NO. 0006	PAGE	JOB NO. DESIGN DATA	PAGE 122
	TITLE		PREPARED CORRY	DATE 12/9/74
		CHECKED		
		APPROVED		

MEASUREMENTS OF INDIVIDUAL HARMONICS

400 HZ THREE PHASE NO LOAD

HARMONIC NUMBER	FREQUENCY HZ	PERCENT OF FUNDAMENTAL	
		L-T-N	L-T-L
1	400	100.0	100.0
5	2000	0.48	0.43
7	2800	0.98	0.80
11	4400	0.88	1.10
13	5200	0.93	0.43
17	6800	0.25	0.33
19	7600	0.33	0.44
23	9200	0.27	0.32
25	10,000	0.22	0.27
29	11,600	0.15	0.18
35	14,000	0.23	0.26
37	14,800	0.10	0.10

MEASURED THD = 2.0%

WAVEFORMS ON PAGES 113 & 114

DISTRIBUTION:

DELCO ELECTRONICS GENERAL MOTORS CORPORATION		REPORT NO. ITEM NO. 0006	PAGE	JOB NO. DESIGN DATA	PAGE 123
TITLE			PREPARED	DATE	
			CORY		12/9/74
			CHECKED		
			APPROVED		

MEASUREMENTS OF INDIVIDUAL HARMONICS

400 HZ THREE PHASE 11KW, PF=1.0 LOAD

HARMONIC NUMBER	FREQUENCY HZ	PERCENT OF FUNDAMENTAL	
		L-T-N	L-T-L
1	400	100.0	100.0
5	2000	1.50	1.45
7	2800	1.20	1.10
11	4400	0.41	1.60
13	5200	1.01	1.60
17	6800	0.24	0.35
19	7600	0.47	0.66
23	9200	0.30	0.40
25	10,000	0.24	0.32
29	11,600	0.16	0.21
35	14,000	0.25	0.24
37	14,800	0.11	0.11

MEASURED THD= 2.5%

WAVEFORMS ON PAGES 115 & 116

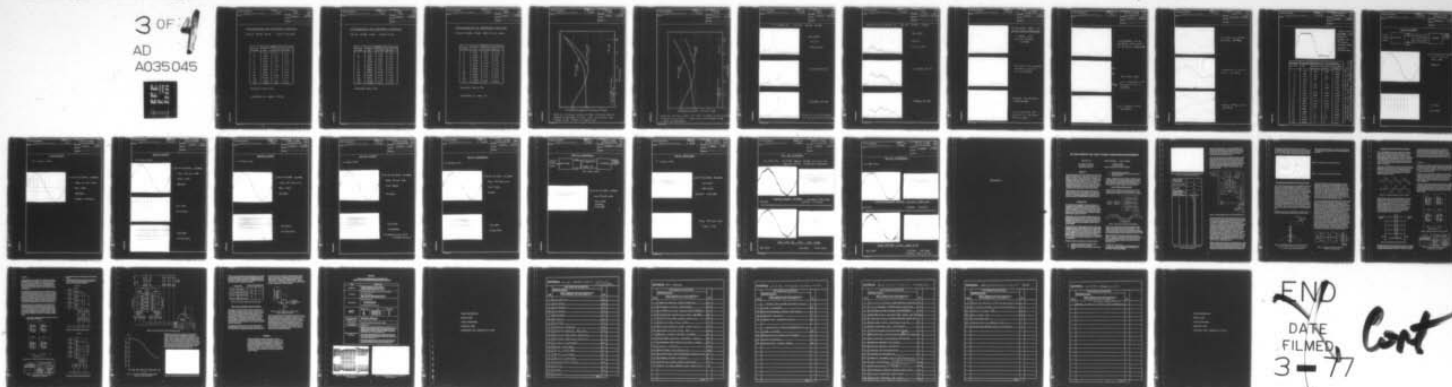
DISTRIBUTION:

AD-A035 045

GENERAL MOTORS CORP GOLETA CALIF DELCO ELECTRONICS DIV F/6 9/5
FREQUENCY CONVERTER PORTABLE, ALTERNATING CURRENT MULTIFREQUENC--ETC(U)
JAN 75 T CORRY DAAK02-72-C-0210
R75-3 NL

UNCLASSIFIED

3 OF 4
AD
A035045



DELCO ELECTRONICS GENERAL MOTORS CORPORATION	REPORT NO. ITEM NO. 0006	PAGE	JOB NO. DESIGN DATA	PAGE 124
	TITLE		PREPARED CORRY	DATE 12/9/74
		CHECKED		
		APPROVED		

MEASUREMENTS OF INDIVIDUAL HARMONICS

400 HZ THREE PHASE 11KW, PF=0.8 LOAD

HARMONIC NUMBER	FREQUENCY HZ	PERCENT OF FUNDAMENTAL	
		L-T-N	L-T-L
1	400	100.0	100.0
5	2000	0.70	0.73
7	2800	1.20	1.10
11	4400	0.80	0.80
13	5200	1.00	1.35
17	6800	0.25	0.31
19	7600	0.52	0.70
23	9200	0.31	0.39
25	10,000	0.26	0.35
29	11,600	0.20	0.23
35	14,000	0.27	0.31
37	14,800	0.12	0.12

MEASURED THD=2.2%

WAVEFORMS ON PAGES 117 & 118

DISTRIBUTION:

DELCO ELECTRONICS GENERAL MOTORS CORPORATION	REPORT NO. ITEM NO. 0006	PAGE	JOB NO. DESIGN DATA	PAGE 125
	TITLE		PREPARED CORY	DATE 12/9/74
		CHECKED		
		APPROVED		

MEASUREMENTS OF INDIVIDUAL HARMONICS

400 HZ THREE PHASE 16 KW, PF=1.0

HARMONIC NUMBER	FREQUENCY HZ	PERCENT OF FUNDAMENTAL	
		L-T-N	L-T-L
1	400	100.0	100.0
5	2000	1.48	1.35
7	2800	2.00	1.95
11	4400	0.89	1.00
13	5200	0.85	1.30
17	6800	0.34	0.46
19	7600	0.46	0.67
23	9200	0.32	0.41
25	10,000	0.26	0.36
29	11,600	0.18	0.23
35	14,000	0.25	0.30
37	14,800	0.13	0.13

MEASURED THD= 3.1%

DISTRIBUTION:

DELCO ELECTRONICS GENERAL MOTORS CORPORATION	REPORT NO. ITEM NO. 0006	PAGE	JOB NO. DESIGN DATA	PAGE 12
	TITLE		PREPARED CORY 12/9/74	DATE
		CHECKED		
		APPROVED		

MEASUREMENTS OF INDIVIDUAL HARMONICS

400 HZ THREE PHASE 16KW, PF=0.8 LOAD

HARMONIC NUMBER	FREQUENCY HZ	PERCENT OF FUNDAMENTAL	
		L-T-N	L-T-L
1	400	100.0	100.0
5	2000	0.93	0.88
7	2800	1.80	1.80
11	4400	1.40	1.50
13	5200	0.63	0.78
17	6800	0.32	0.40
19	7600	0.50	0.60
23	9200	0.32	0.37
25	10,000	0.20	0.20
29	11,600	0.20	0.20
35	14,000	0.28	0.30
37	14,800	0.11	0.11

MEASURED THD = 2.9%

WAVEFORMS ON PAGE 121

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

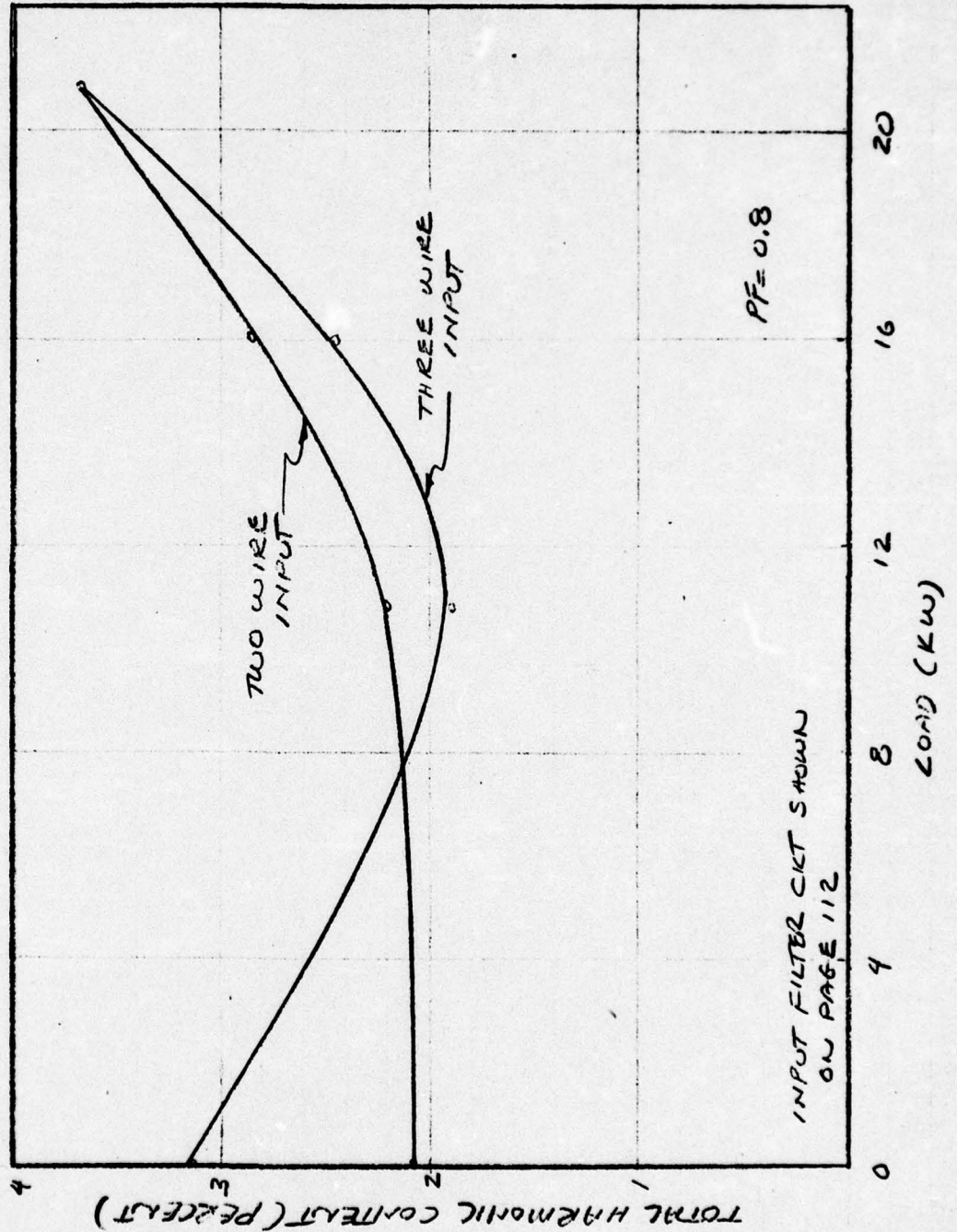
REPORT NO.
ITEM NO.
0006

PAGE JOB NO.
DESIGN
DATA

PAGE
127

TITLE

PREPARED
CORRY 12/11/79
DATE
CHECKED
APPROVED



PLOTS OF HARMONIC CONTENT OF THE INVERTER OUTPUT
VOLTAGE WAVEFORMS VS LOAD FOR TWO WIRE AND
THREE WIRE INPUT CONNECTIONS

DISTRIBUTION:

DELCO ELECTRONICS
GENERAL MOTORS CORPORATION

REPORT NO.
ITEM NO.
0006

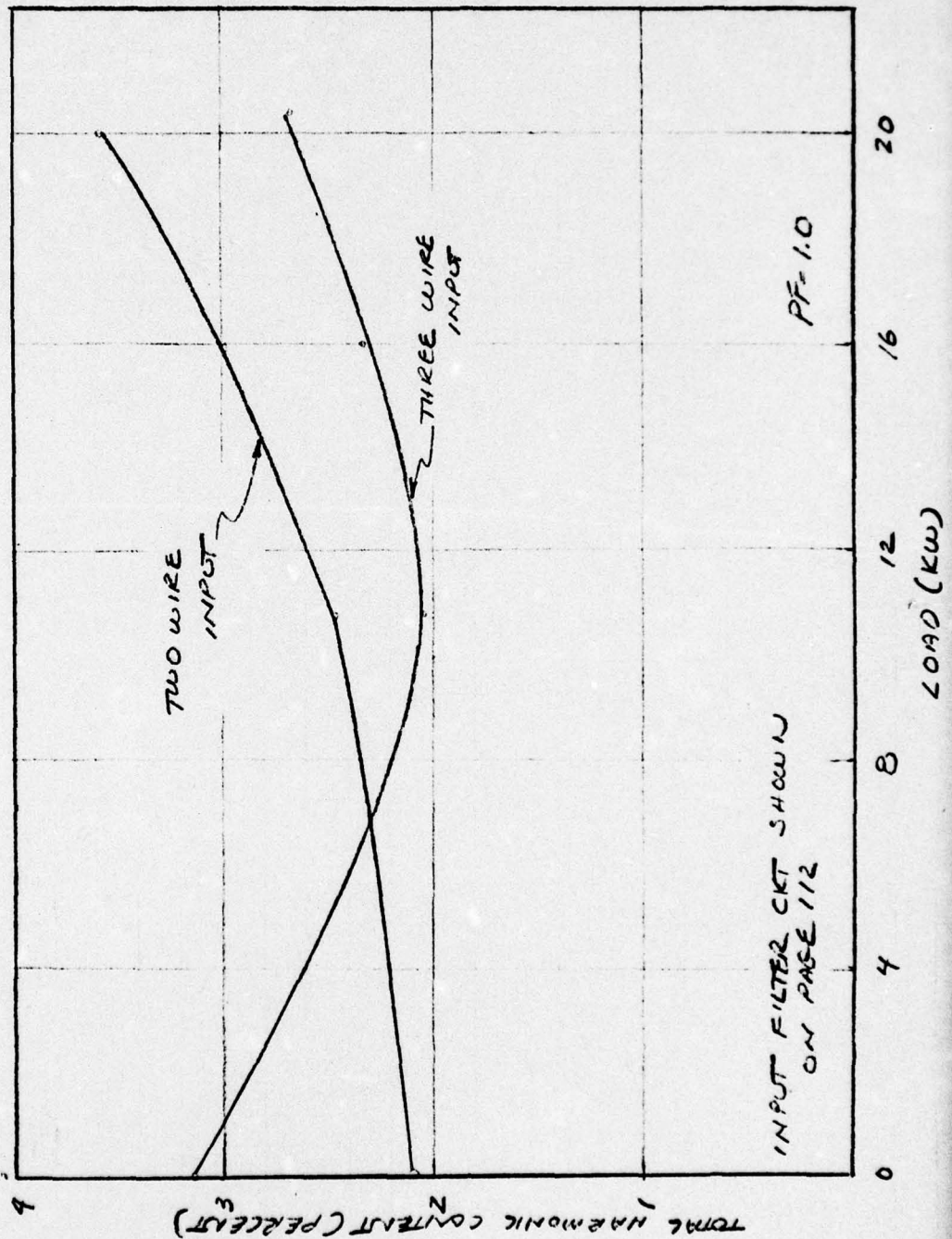
PAGE JOB NO.
DESIGN
DATA

TITLE

PREPARED
CORR-1 12/11/

CHECKED

APPROVED



PLOTS OF HARMONIC CONTENT OF THE INVERTER OUTPUT VOLTAGE WAVEFORMS VS LOAD FOR TWO WIRE AND THREE WIRE INPUT CONNECTIONS.

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.

0006

PAGE

JOB NO.

DESIGN

DATA

PAGE

129

TITLE

PREPARED

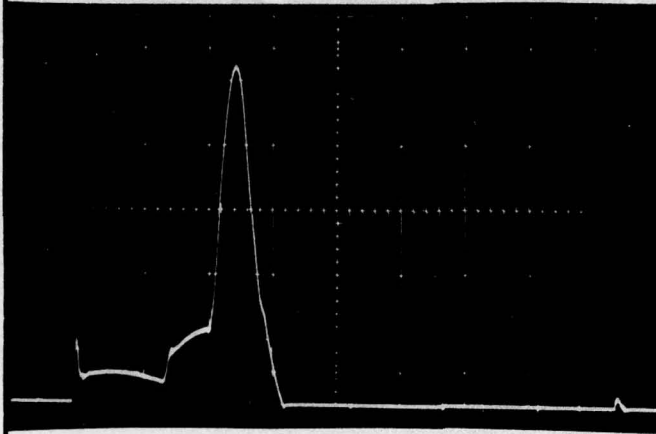
CORR-1 12/13/74

DATE

CHECKED

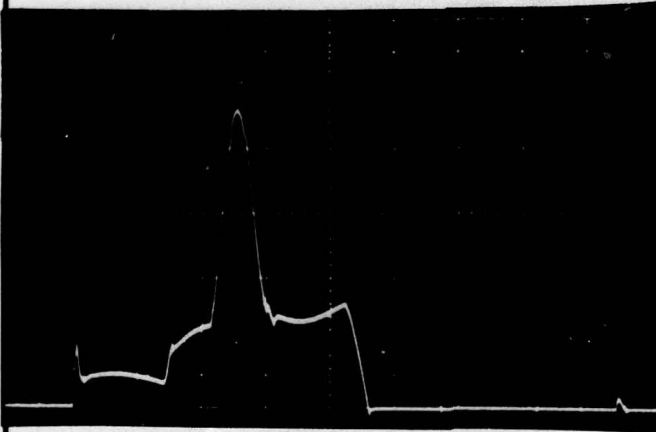
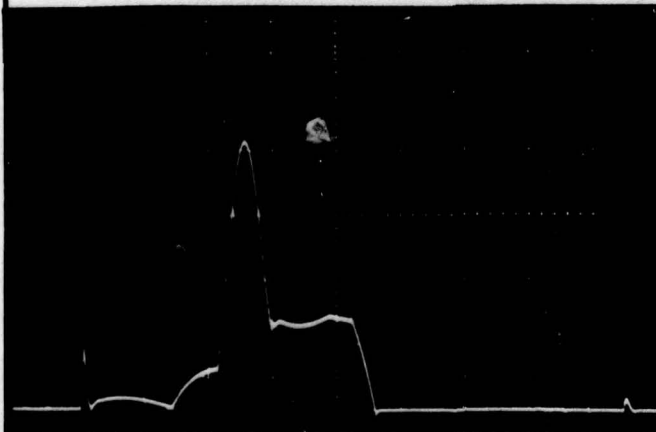
APPROVED

T-CURRENT 400HZ THREE PHASE

NO LOAD

50A/DIV.

50μSEC/DIV.

20.6KW, PF=1.020.6KW, PF=0.8(2 WIRE INPUT; 60 MFD
L-T-L OUTPUT CAPACITANCE)

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.

0006

PAGE

JOB NO.

SIGN
DATA

PAGE

130

TITLE

PREPARED

CORRY

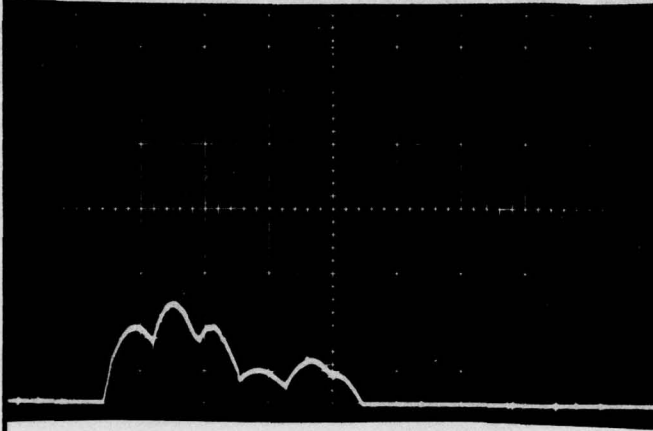
DATE

12/13/79

CHECKED

APPROVED

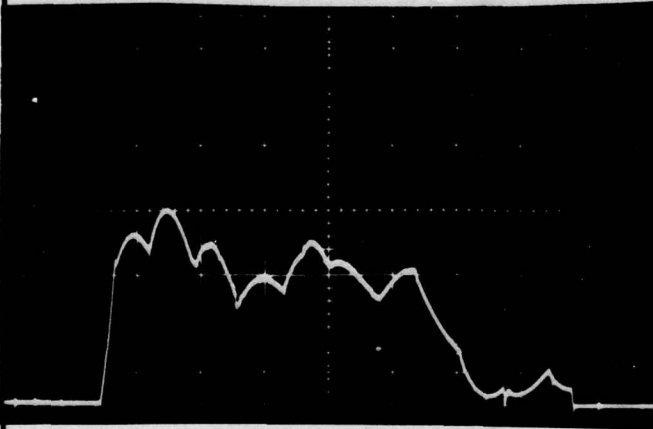
POWER CENTER CURRENT PC 400 HZ THREE PHASE



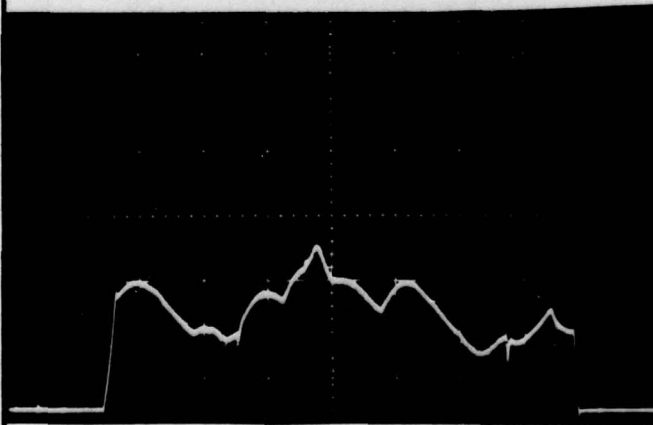
NO LOAD

50A/DIV.

100μSEC/DIV.



20.6 KW, PF=1.0



20.6 KW, PF=0.8

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.
ITEM NO.
0006

PAGE JOB NO.
BASIC VOLTAGE
WAVEFORMS

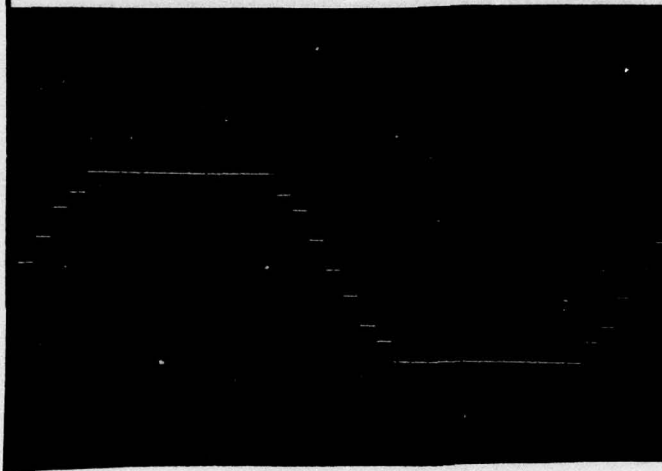
PAGE
131

TITLE

PREPARED CORRY DATE 12/16/74

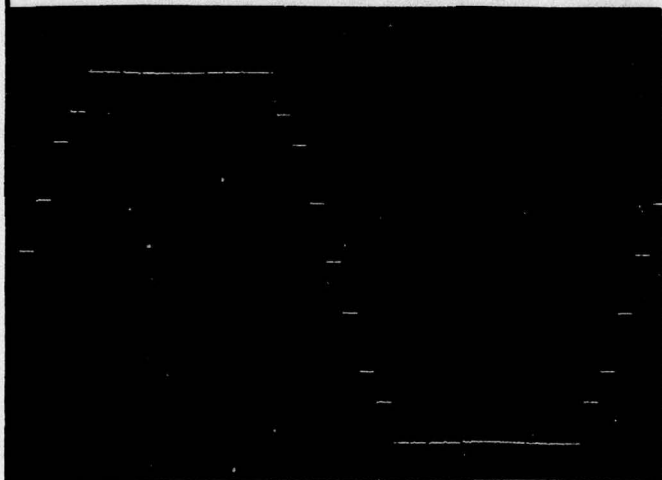
CHECKED

APPROVED

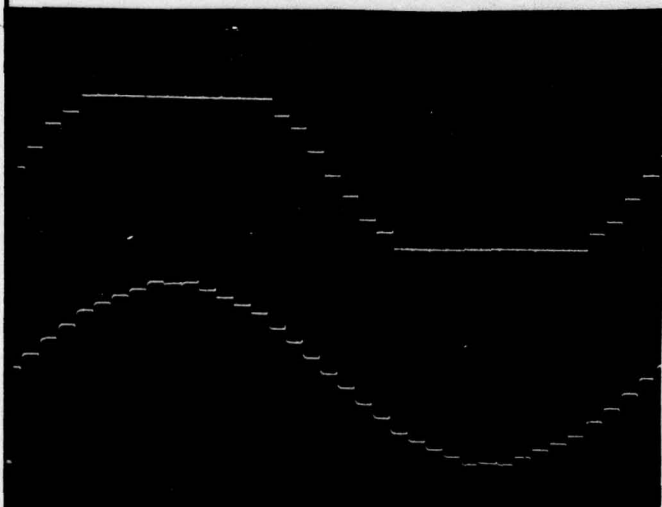


PHOTOGRAPHS TAKEN AT
60 HZ, 115V, PF=1.0 LOAD

INVERTER BASIC
LINE-TO-NEUTRAL
VOLTAGE



BASIC LINE-TO-NEUTRAL
VOLTAGE EXPANDED
IN AMPLITUDE

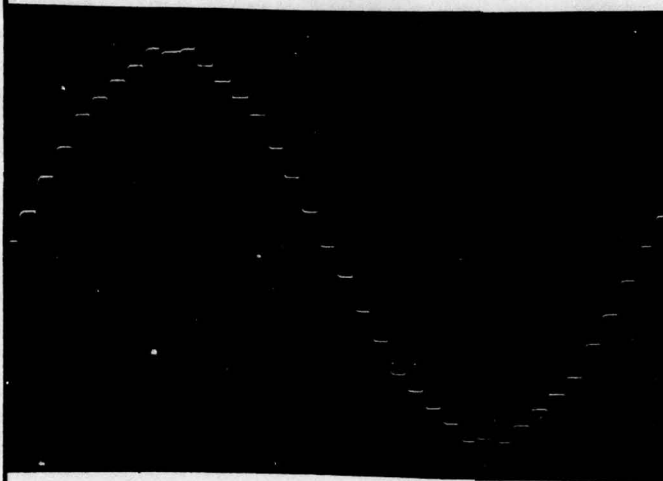


VOLTAGE INTO TRIPLEN
ATTENUATOR

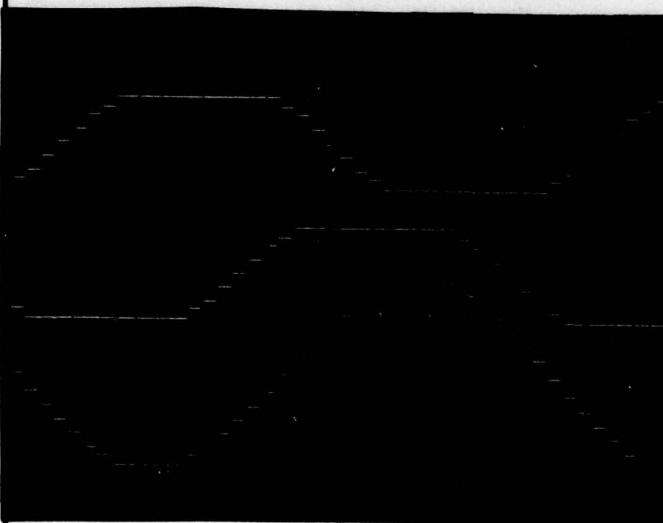
L-T-N VOLTAGE AT
OUTPUT OF TRIPLEN
ATTENUATOR

DISTRIBUTION:

DELCO ELECTRONICS GENERAL MOTORS CORPORATION	REPORT NO. ITEM NO. 0006	PAGE	JOB NO. BASIC VOLTAGE WAVEFORMS	PAGE 132
	TITLE		PREPARED CORRY	DATE 12/16/79
		CHECKED		
		APPROVED		



UNFILTERED L-T-N
VOLTAGE AT OUTPUT
OF TRIPLE L ATTENUATOR



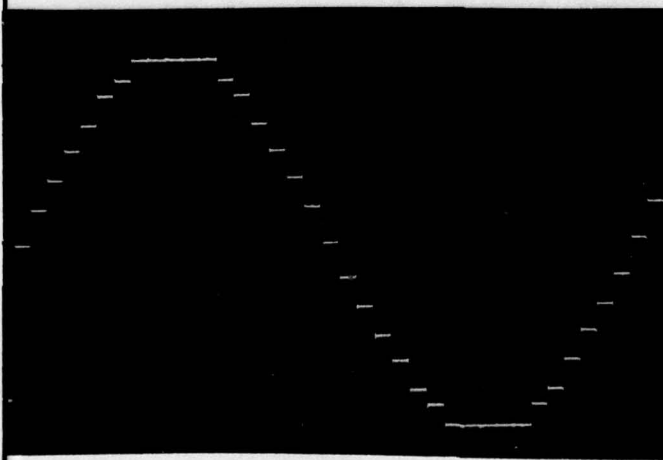
V_{an}

V_{bn}

$$V_{an} + V_{bn} = V_{ab}$$

V_{ab} L-T-N VOLTAGES AND
RESULTANT L-T-L
VOLTAGE

UNFILTERED L-T-L
VOLTAGE



DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.
ITEM NO.
0006

PAGE JOB NO.
BASIC VOLTAGE
WAVEFORMS

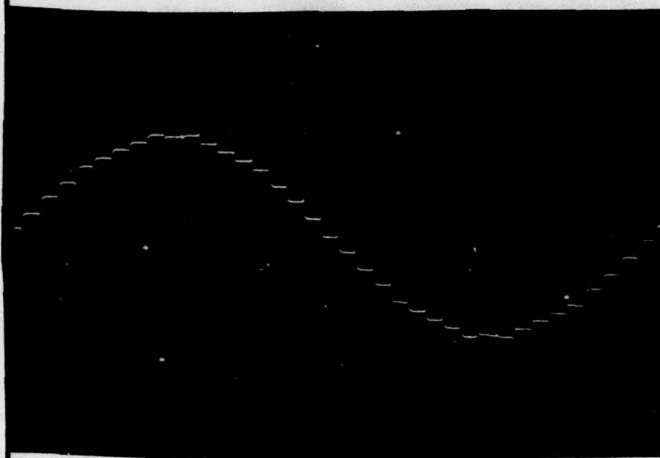
PAGE
133

TITLE

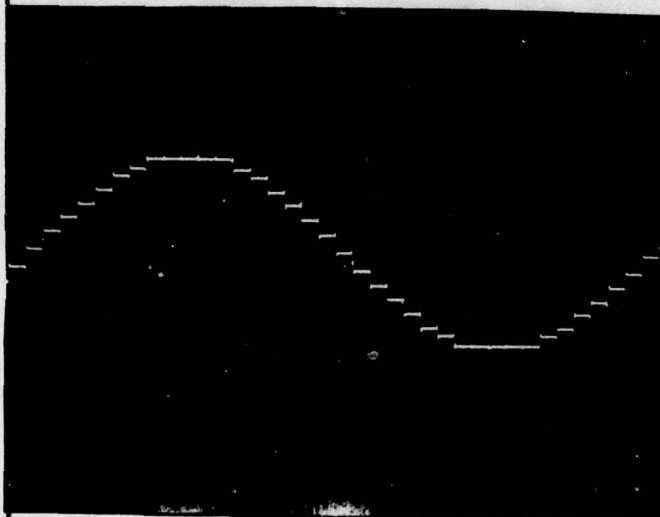
PREPARED CORRY 12/16/74 DATE

CHECKED

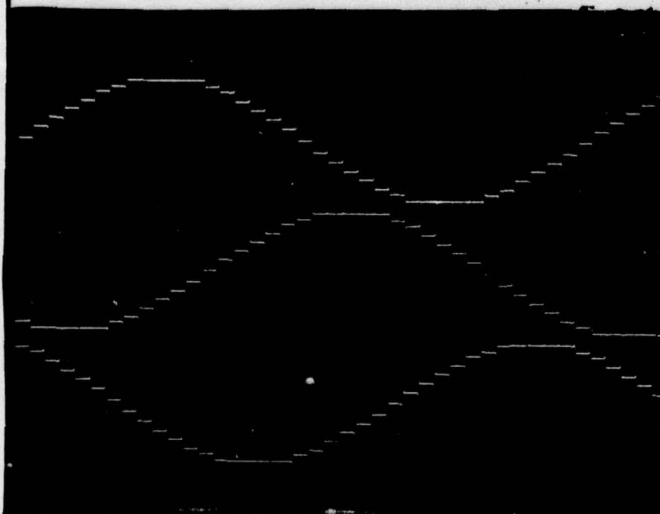
APPROVED



UNFILTERED LINE-TO-
NEUTRAL VOLTAGE



UNFILTERED LINE-TO-
LINE VOLTAGE

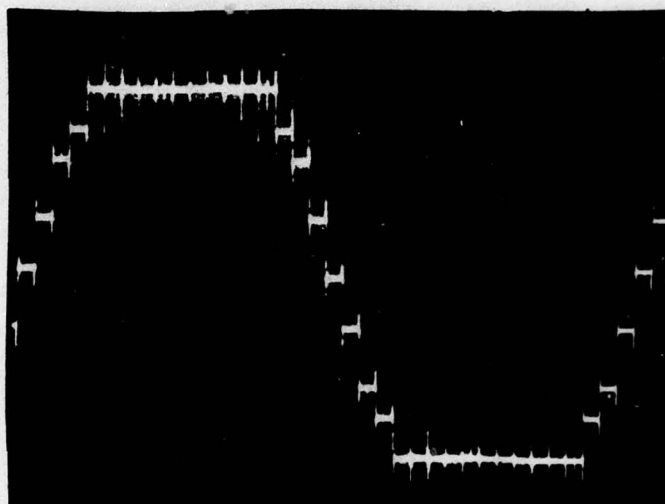


THREE PHASE L-T-L
VOLTAGES

DISTRIBUTION:

TITLE

PREPARED CORRY 12/16/74
CHECKED
APPROVED



BASIC L-T-N
VOLTAGE WITH
INTENSITY
TURNED UP
TO SHOW
HIGHER FRE-
QUENCY
HARMONICS

HARMONIC NUMBER	FREQUENCY HZ	PERCENT OF FUNDAMENTAL		
		MEASURED* L-T-N	MEASURED* L-TL	COMPUTED L-T-N OR L-T-L
1	60	100.0	100.0	100.0
3	180	0.1	—	18.63
5	300	0.8	0.8	0.98
7	420	1.5	1.5	1.46
9	540	—	—	3.24
11	660	0.8	0.8	0.96
13	780	0.45	0.44	0.21
15	900	—	—	1.17
17	1020	0.87	0.87	0.65
19	1140	0.58	0.60	0.54
21	1260	—	—	0.86
23	1380	0.40	0.40	0.16
25	1500	0.37	0.36	0.43
29	1740	0.30	0.30	0.15
31	1860	—	0.1	0.12
33	1980	—	—	1.63
35	2100	3.0	3.0	2.88
37	2220	2.5	2.6	2.71
39	2340	—	—	1.37
41	2460	—	—	0.10

* MEASUREMENTS MADE AT OUTPUT OF TRIPLEX
ATTENUATOR. LOAD = 11KW, PF=1.0. IMPED CAP L-T-N
MEASURED THD=5.3%. COMPUTER DESIGNED WAVEFORM THD=5.6%

DISTRIBUTION:

TITLE

PREPARED

CORRY

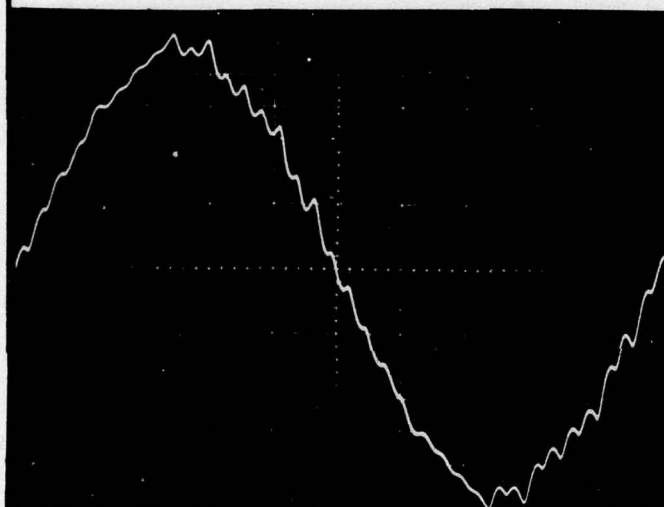
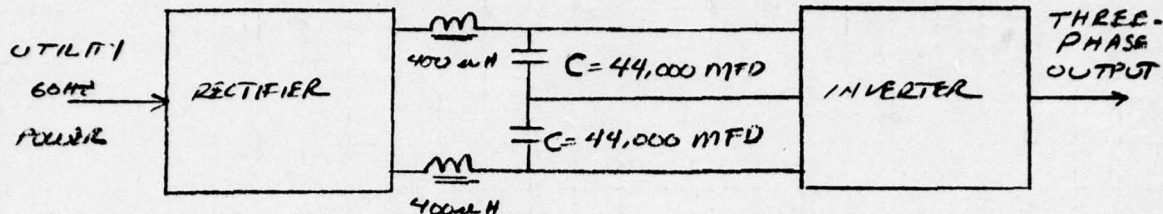
DATE

1/2/75

CHECKED

APPROVED

60 HZ OUTPUT

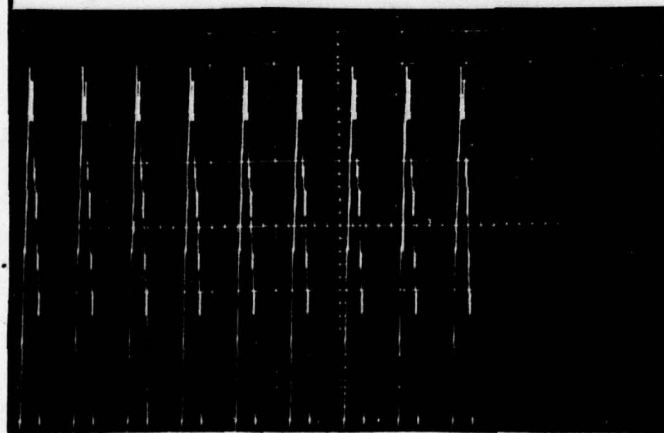


LINE-TO-NEUTRAL VOLTAGE

11kW, PF=0.8 LOAD

THD = 4.3%

50V / DIV.



20V / DIV.

20ms / DIV.

DISTRIBUTION:

TITLE

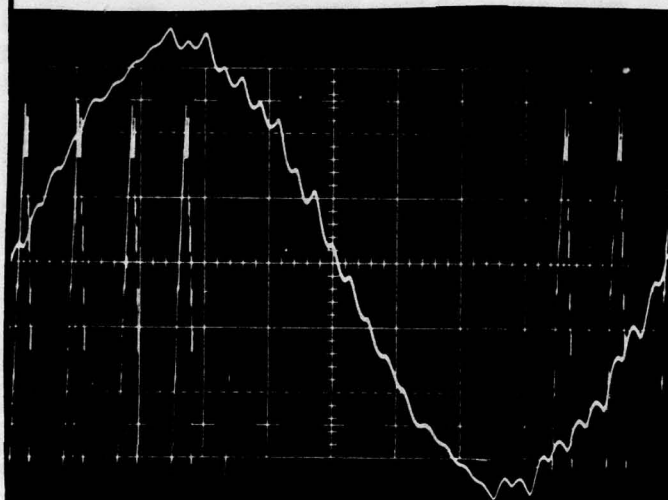
PREPARED CORRY DATE 1/2/75

CHECKED

APPROVED

60 Hz OUTPUT

$C = 22,000 \text{ MFD.}$



LINE-TO-NEUTRAL VOLTAGE

11KW, PF=0.8 LOAD

THD = 4.3%

50V/DIV.

20V/DIV. 20MS/DIV.

DISTRIBUTION:

DELCO ELECTRONICS

GENERAL MOTORS CORPORATION

REPORT NO.

ITEM NO.

0006

PAGE

JOB NO.

INPUT FILTER
EXPERIMENTS

PAGE

137

TITLE

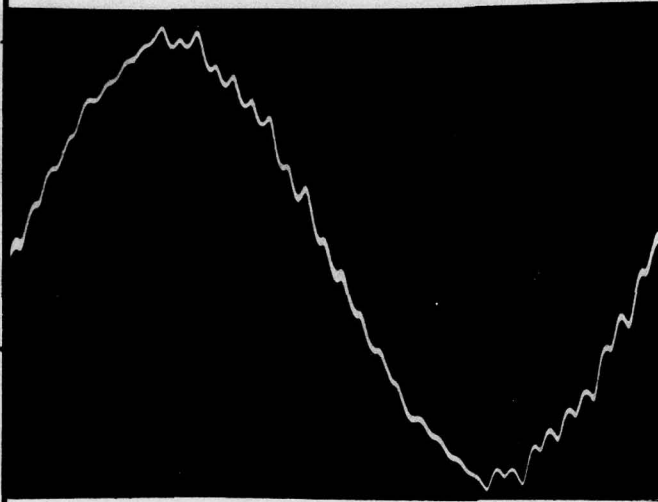
PREPARED

CORRY 1/2/75

DATE

CHECKED

APPROVED

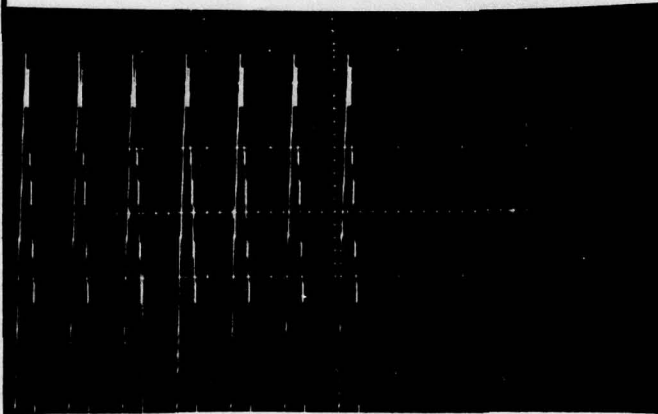
60 HZ OUTPUT $C = 11,000 \text{ MFD.}$ 

LINE-TO-NEUTRAL VOLTAGE

11KV, PF=0.8 LOAD

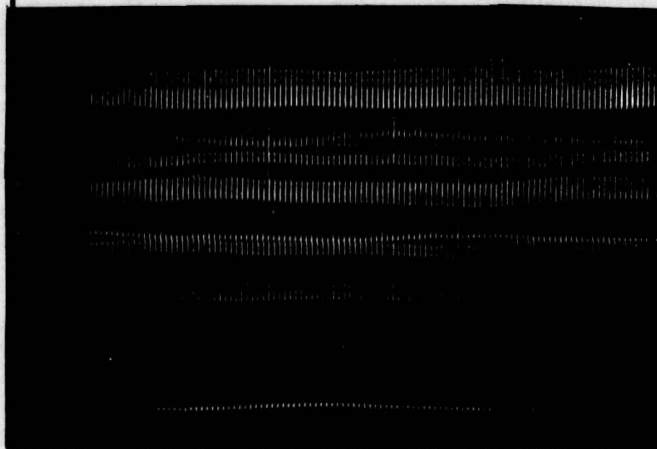
THD= 4.5%

50V/DIV.



20V/DIV.

20ms/DIV.



20V/DIV.

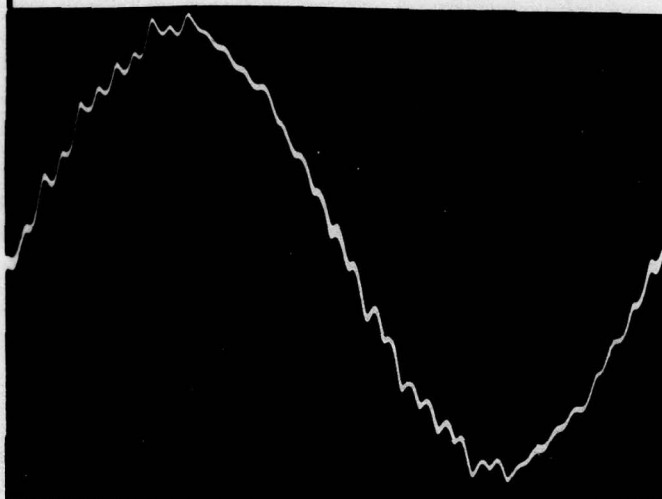
0.2 SEC/DIV.

DISTRIBUTION:

DELCO ELECTRONICS GENERAL MOTORS CORPORATION	REPORT NO. ITEM NO. 0006	PAGE	JOB NO. INPUT FILTER EXPERIMENTS	PAGE 138
	TITLE		PREPARED CORRY	DATE 1/2/75
		CHECKED		
		APPROVED		

60 HZ OUTPUT

$C = 8,800 \text{ MFD.}$

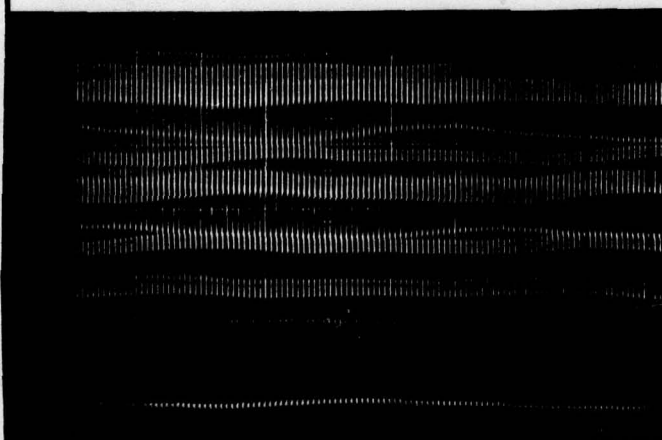


LINE-TO-NEUTRAL VOLTAGE

11KW, PF=0.8 LOAD

THD = 4.4%

50V/DIV.



20V/DIV.

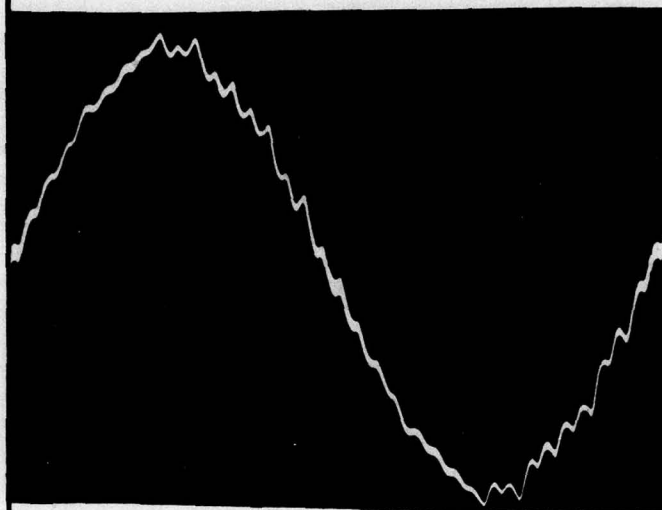
0.2 SEC/DIV.

DISTRIBUTION:

DELCO ELECTRONICS GENERAL MOTORS CORPORATION	REPORT NO. ITEM NO. 0006	PAGE	JOB NO. INPUT FILTER EXPERIMENTS	PAGE 139
	TITLE		PREPARED CORRY 1/2/75	DATE
		CHECKED		
		APPROVED		

60 HZ OUTPUT

$C = 6,600 \text{ MFD.}$

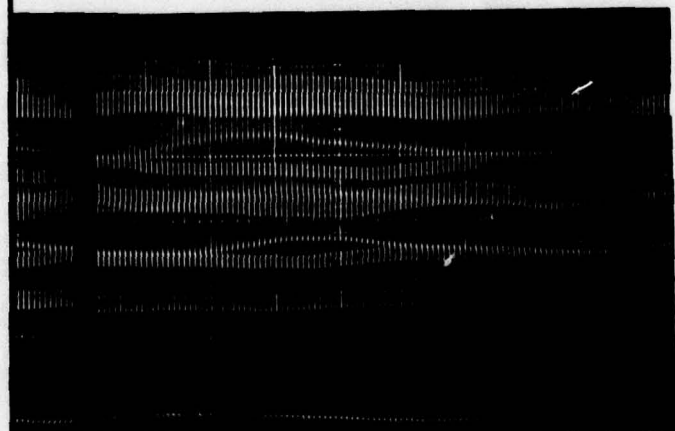


LINE-TO-NEUTRAL VOLTAGE

11KW, PF=0.8 LOAD

$\text{TID} = 4.6\%$

50V/DIV.



20V/DIV.

0.2 SEC/DIV.

(RIPPLE $\times 4$ VOLTS P-TP
 $\approx 0.6 \text{ SEC/CYCLE}$)

DISTRIBUTION:

DELCO ELECTRONICS
GENERAL MOTORS CORPORATION

REPORT NO.
ITEM NO.
0006

PAGE JOB NO.
INPUT FILTER
EXPERIMENTS
190

TITLE

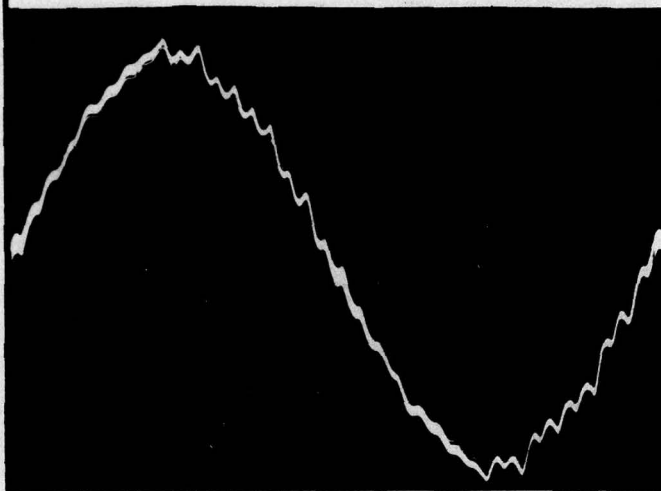
PREPARED
CORRY 1/2/75

CHECKED

APPROVED

60 HZ OPERATION

$C = 4,400 \text{ MFD.}$

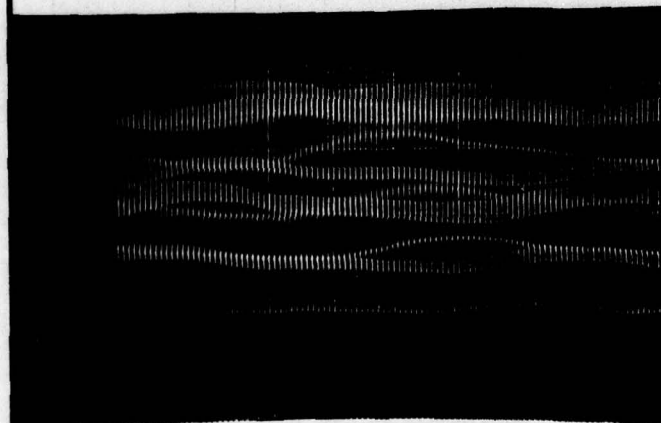


LINE-TO-NEUTRAL VOLTAGE

11KW, PF=0.8 LOAD

THD=4.6%

50V/DIV.



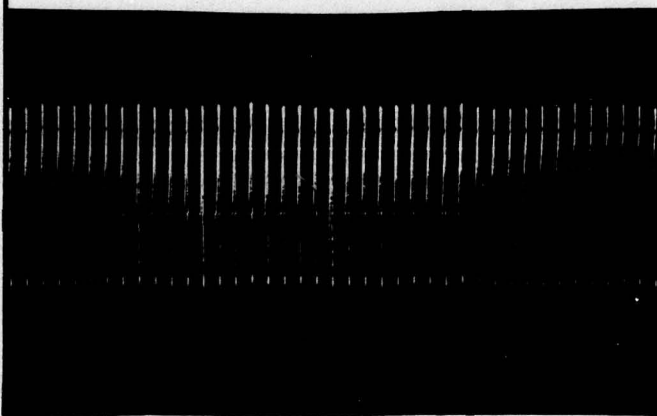
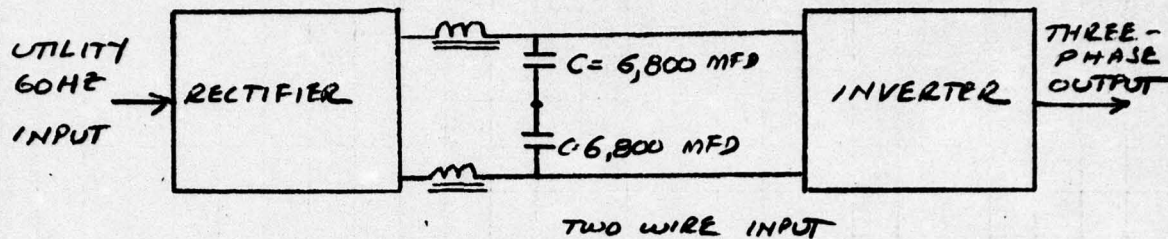
20V / DIV.

0.2 SEC / DIV.

DISTRIBUTION:

DELCO ELECTRONICS GENERAL MOTORS CORPORATION	REPORT NO. ITEM NO. 0006	PAGE	JOB NO. INPUT FILTER EXPERIMENTS	PAGE 141
	TITLE		PREPARED CORRY 11/2/75	DATE
		CHECKED		
		APPROVED		

400 HZ OPERATION



LINE-TO-NEUTRAL VOLTAGE

11KW, PF=0.8 LOAD

THD=2.6%

20V/DIV.

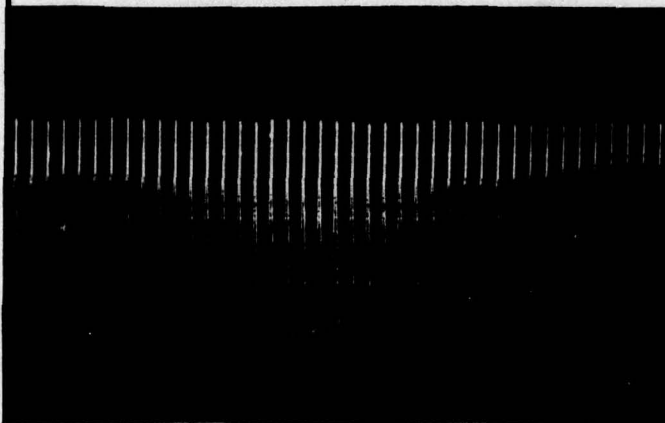
10MS/DIV.

DISTRIBUTION:

DELCO ELECTRONICS GENERAL MOTORS CORPORATION	REPORT NO. ITEM NO. 0006	PAGE	JOB NO. INPUT FILTER EXPERIMENTS	PAGE 142
	TITLE		PREPARED CORY	DATE 1/2/75
		CHECKED		
		APPROVED		

400 HZ OPERATION

$C = 4,400 \text{ MFD.}$

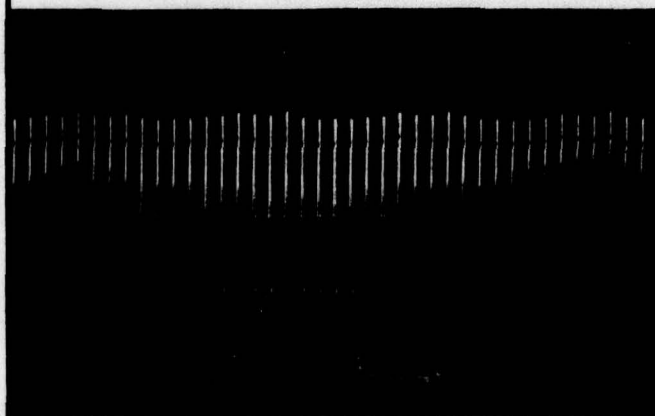


LINE-TO-NEUTRAL VOLTAGE

NO LOAD

THD = 2.2%

20V/DIV. 10MS/DIV.



11KW, PF=0.8 LOAD

THD = 2.7%

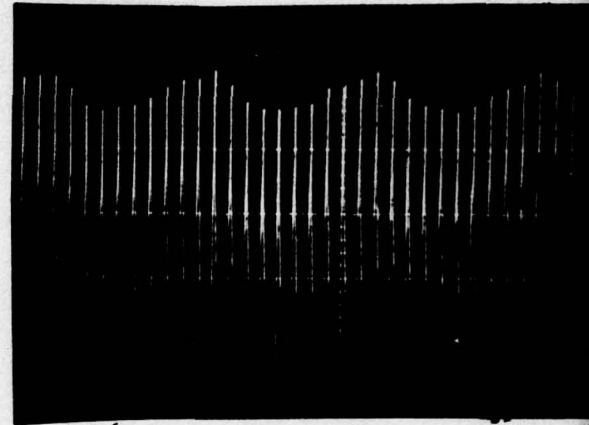
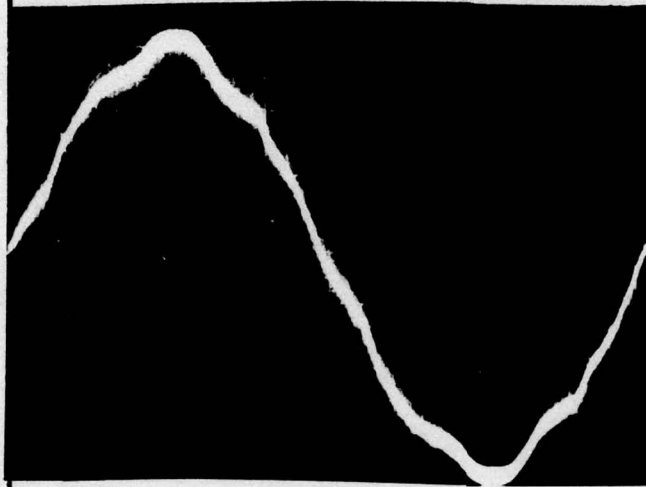
DISTRIBUTION:

TITLE

PREPARED CORRY 11/2/75
CHECKED
APPROVED

400 HZ OPERATION

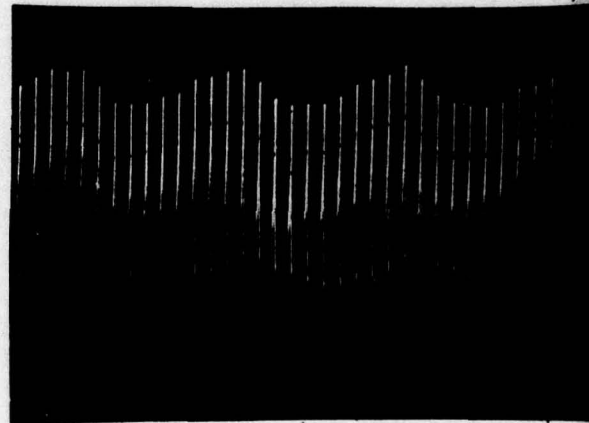
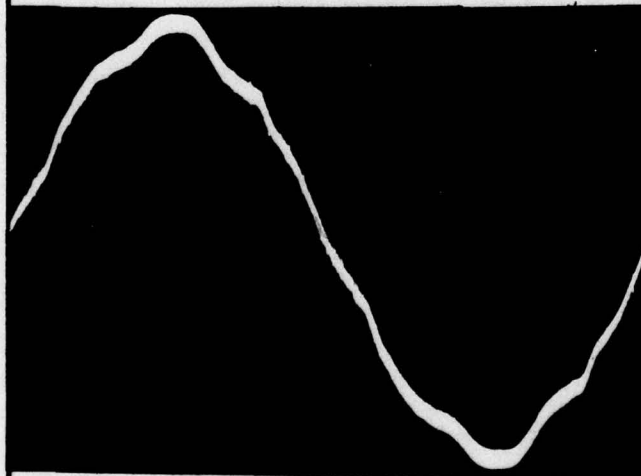
$C = 250 \text{ MFD.}$ (INVERTER DOESNT OPERATE WITH $C = 0 \text{ MFD.}$
BECAUSE OF P.F. CORRECTION OPERATION)



LINE-TO-NEUTRAL VOLTAGE , NO LOAD, THD = 4.6%

50V / DIV.

20V / DIV. 10 MS / DIV.



11KW, PF = 0.8 LOAD THD = 4.6%

50V / DIV.

20V / DIV. 10 MS / DIV.

DISTRIBUTION:

DELCO ELECTRONICS
GENERAL MOTORS CORPORATION

REPORT NO.
ITEM NO.
0006

PAGE JOB NO.
INPUT FILTER
EXPERIMENTS

PAGE
144

TITLE

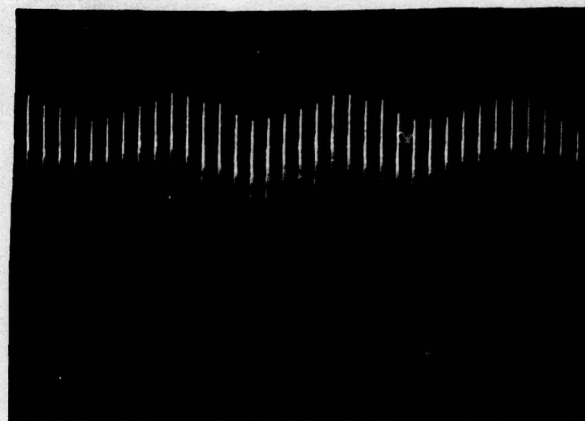
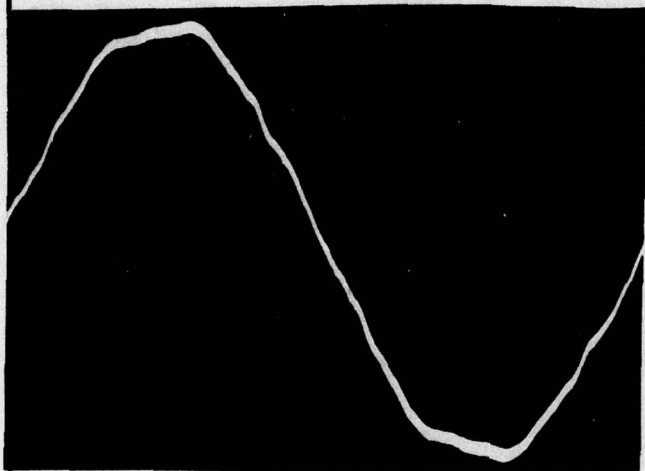
PREPARED
CORRY 1/21/75

CHECKED

APPROVED

400 HZ OPERATION

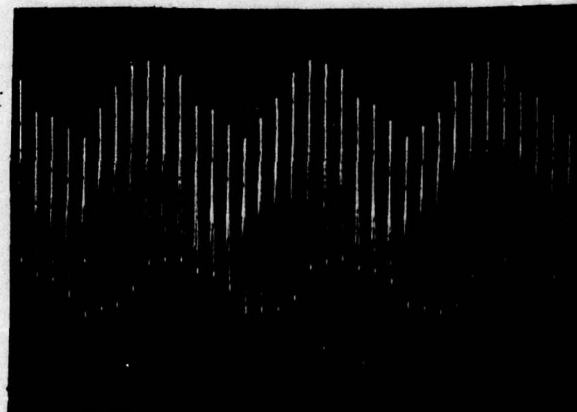
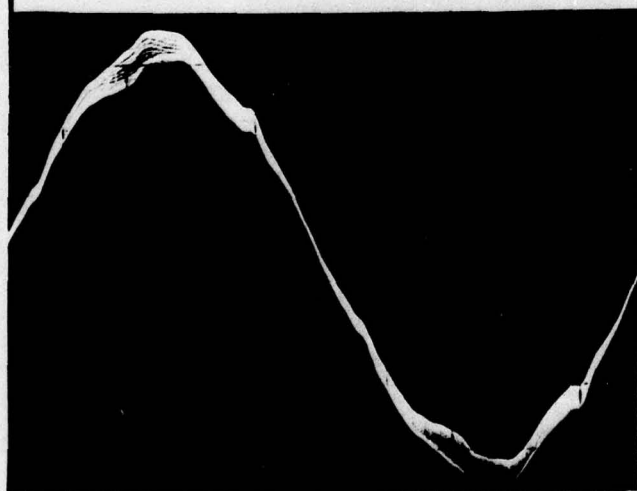
$C = 500 \text{ nFD.}$



LINE-TO-NEUTRAL VOLTAGE, NO LOAD, THD = 3.4%

50V/DIV.

20V/DIV. 10ms/DIV.



11KW, PF = 0.8 LOAD, THD = 5.7%

50V/DIV.

20V/DIV. 10ms/DIV.
(RIPPLE FREQ \approx 40 HZ)

DISTRIBUTION:

APPENDIX B

DC LINK INVERTER FOR ARMY POWER CONDITIONER REQUIREMENTS

Thomas M. Corry

Delco Electronics Division
General Motors Corporation
Santa Barbara, California

Robert M. McKechnie

Robert A. Williams

United States Army
Ft. Belvoir, Virginia
Mobility Equipment R & D Center (MERDC)

ABSTRACT

This paper describes the 12.5 kVA dc link inverter being developed by Delco Electronics—Santa Barbara Operations for USA MERDC, Ft. Belvoir, Virginia. The inverter can produce 120/208 volts three-phase, 120 volts single-phase, or 120/240 volts single-phase power at 60 or 400 Hz. It has an efficiency of 84 to 94% and a breadboard weight of 150 pounds. Based on a patented design concept (No. 3,725,767), the inverter generates stepped wave and square wave voltage segments which are combined as a three-phase composite to produce line-to-line waveforms of 4% total harmonic content before filtering.

Study results show that the basic inverter concept can take several circuit forms, and can be developed with ratings up to 100 kVA. The inverter is being developed as a candidate for the Army 15 kVA general purpose power conditioner, and as such must conform to MIL-STD-1332B and MIL-STD-461A.

INTRODUCTION

The United States Army Mobility Equipment Research and Development Center (MERDC) is sponsoring development of a family of "stand alone" electric power conditioners. Of the approaches available the dc link inverter appears highly feasible in the 3 to 300 kVA power range. Part of this effort is being performed by the Delco Electronics—Santa Barbara Operations under Contract DAAK 02-72-C-0210.

Development of the dc link inverter concept has been concentrated in the medium power range (15 - 30 kVA) wherein most immediate Army requirements lie. Study results clearly show the feasibility and utility of this approach for high power range (100 kVA) applications, and the significant circuit improvements attainable.

The family of power conditioners envisioned by the Army will supply multifrequency (60 Hz/400 Hz) outputs at multivoltages (120/208 volts, three phase for all ratings, and in addition 120/240 volts, single phase for ratings below 15 kVA), and function as uninterruptable power systems (UPS) when a suitable battery supply is added. The output power quality will conform to MIL-STD-1332B even though the input power is of lesser quality, or of a special type (such as the high frequency of the 12.5 kVA turbo-alternator).

Therefore, the power conditioners have potential usage as:

- Line phase converter (1 ϕ to 3 ϕ or vice versa)
- Frequency converters (60 to 400 Hz)
- Precision power sources, operating from utility grade power

- Uninterruptable power systems
- Special purpose systems (such as a turbo-alternator frequency changer)

A paper * describing the work undertaken to develop a power conditioner for the turbo-alternator application was presented to the 1973 PESC. This work showed the suitability of the Delco approach for general purpose power conditioners. Additional efforts toward this application are described below.

BASIC THREE-PHASE INVERTER

The basic inverter concept is a three-phase, four-wire system consisting of power switching circuits that generate x, y, and center functions, as defined by the voltage waveform in Figure 1.

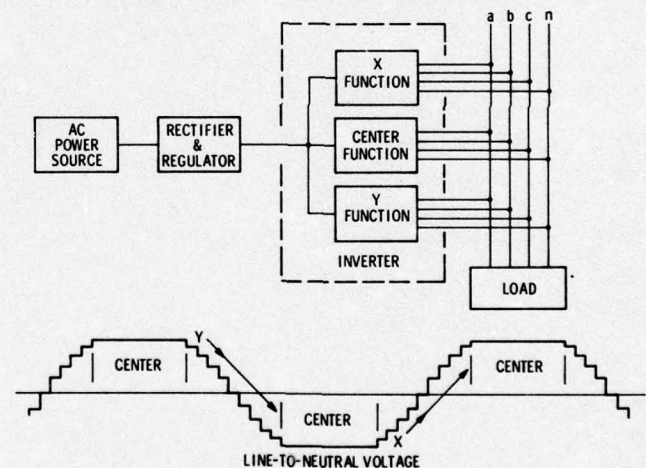


Figure 1. Delco Power Conditioner Block Diagram

Figure 2 is an oscilloscope trace of the flat topped waves generated in a three-phase, line-to-neutral voltage pattern. The waveform has a total harmonic content of 16.9% and consists of only odd harmonics. Removal of the third harmonic (16.02%), and all remaining triplens, reduces total harmonic content to 4.2%.

Individual harmonics of the inverter waveform are shown in Table I. Note the low values of the fifth and seventh harmonics. The only single harmonic of significance is the 41st, which is generated by the stepped character of the output wave and is easily filtered out.

* T.M. Corry. "A New Concept for Generating Three-Phase Sine Wave Voltages With Semiconductor Power Switches." 1973 PESC. Record pages 230-236.



Figure 2. Three-Phase Line-to-Neutral Voltages Generated by the y, x, and Center Function Circuits

LINE-TO-NEUTRAL VOLTAGE LEVELS	6
POWER CENTER WIDTH	990
STEP WIDTH	90
TOTAL HARMONIC CONTENT OF UNFILTERED OUTPUT VOLTAGE	16.9%
INDIVIDUAL HARMONICS	MAGNITUDE (%)
1	100.0
3	16.02
5	0.19
7	0.61
9	1.06
11	0.65
13	0.51
15	0.40
17	0.36
19	0.33
21	0.27
23	0.30
25	0.22
27	0.27
29	0.22
31	0.34
33	0.11
35	0.01
37	1.28
39	2.59
41	2.45
43	1.10
45	0.07
47	0.07
49	0.21
51	0.12
53	0.13
55	0.09
57	0.12
59	0.09
61	0.09

Table 1. Harmonic Content of the MERDC 10 kW Inverter Voltage Waveforms

Figure 3 is a schematic diagram of the original MERDC 12.5 kVA inverter showing the y, x, and center function circuits. Three-phase power is rectified and filtered at the input of the inverter. The inverter consists of y, x, and center function circuits, phase selectors and output filter.

The center function generator is a three-phase thyristor bridge circuit through which as much as 80% of the inverter power passes directly from the input to the output. The remaining power passes through the y and x step forming circuits, consisting of a tapped autotransformer, step selector switches and a thyristor circuit that energizes the autotransformer. The phase selectors apply the stepped voltage waveforms to the proper output lines.

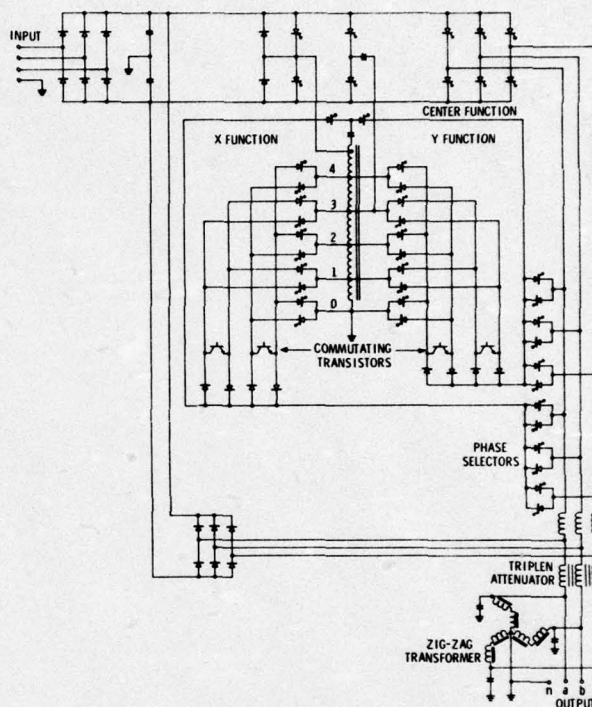


Figure 3. Original MERDC 10 kW Inverter Breadboard Circuit

The triplen attenuator and zig-zag transformer shown in Figure 3 form a circuit of magnetic components that removes the third harmonic and all multiples thereof from the line-to-neutral output voltages. The attenuator is three isolated windings on a common "C" core that function as current limiting impedances to all triplen frequencies in the three-phase output leads. With balanced loads, the harmonic currents in the three windings caused by the fundamental and all odd harmonics other than the triplens are each 120° out of phase. They cancel, and therefore do not induce back-EMFs in the windings. Therefore, the windings appear as air core inductors to the non-triplen frequencies with inductances of a few microhenries. Since the inductance is low to the fundamental, stored energy is low and inverter regulation is not significantly degraded. In contrast, triplen harmonic currents are additive and are limited in magnitude to the core magnetizing current.

While the triplen attenuator serves as a high impedance to triplen currents, the zig-zag autotransformer presents essentially a short circuit to these currents. The relative impedances of the triplen attenuator and the zig-zag transformer are such as to reduce the magnitude of the third harmonic voltage from 16.02% at the

inverter to less than 0.3% at the output. This reduction is accomplished with relatively small investment in size and weight and very low energy storage. The oscilloscope traces in Figures 4a and 4b show the results of eliminating the triplen harmonics

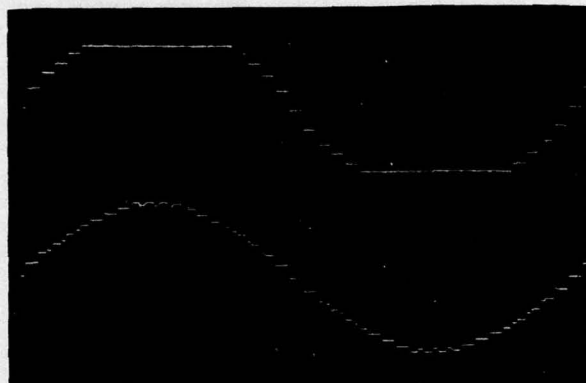


Figure 4a. Voltage at Input of Triplen Attenuator

Figure 4b. Voltage at Output of Triplen Attenuator

THE PROBLEM OF OBTAINING SINGLE-PHASE POWER

As well as producing three-phase power, the MERDC breadboard inverter is now required to produce 10 kW, 0.8 PF, two-wire, 120 volts or three-wire 120/240 volts, at 60 Hz or 400 Hz. The problem was to supply this load unbalance without significantly degrading voltage output quality, efficiency, or transient response. All power handling components in the inverter are sized principally by the magnitude of the load. The size of the zig-zag transformer, however, is determined primarily by the magnitude of load unbalance. For balanced three-phase loads, the zig-zag transformer is essentially unloaded. When a single-phase load is connected line-to-neutral, the transformer maintains currents in the windings equal to one-third the load current. Thus, the rating of the zig-zag transformer is a major factor in determining the magnitude of the 120 volts, two-wire, single-phase loads that are acceptable. Figure 5 depicts the vector relationships between line currents and line-to-neutral voltages for a 120V single-phase load.

Through the action of the zig-zag transformer, current is forced to flow in all three phases of the inverter. This action helps

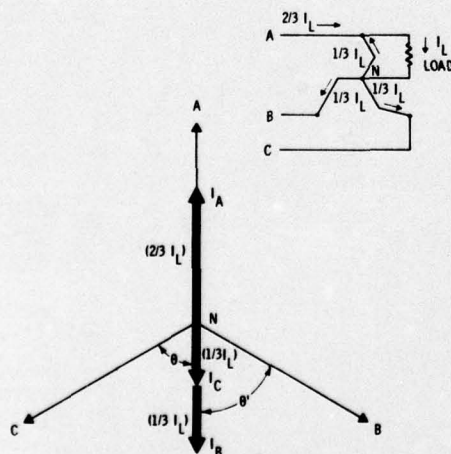


Figure 5. Vector Relationships: Line Currents and Line-to-Neutral Voltages for a Single-Phase Load Connected to the Inverter Output Zig-Zag Transformer

from the line-to-neutral voltages, by means of the triplen attenuator and zig-zag transformers, to form a nearly sinusoidal output voltage.

maintain voltage balance across the three phases; but more important, the currents in the unloaded phases are forced in magnitude and phase angle to cancel the ampere turns in the triplen attenuator core due to the fundamental current in the loaded phase. In Figure 5, the current in line A is $2/3$ the load current, and is in phase with that line-to-neutral voltage. The current in line B is $1/3$ the load current and lags its phase voltage by 60° . Two-thirds of the load power is delivered by line A and $1/6$ of the power is delivered by each of lines B and C through action of the zig-zag transformer. Line A carries twice the current compared to rated three-phase loading.

Thus it can be seen that single-phase, 120 volts, two-wire loading of the inverter is achievable without modifying the circuit configuration, but that the magnitude of the unbalanced load is limited primarily by the volt-ampere rating of the zig-zag output transformer. The single-phase 120/240 volts output is not inherently available to the basic inverter design. However, a single-phase autotransformer, connected line-to-line and tapped to produce 120 volts, two-wire or 120/240 volts, three-wire, can be designed to carry rated power and operate efficiently at both 60 and 400 Hz. When single-phase loads are connected line-to-line, the zig-zag transformer does not handle the unbalance and is essentially unloaded. Studies and tests indicate that the most efficient, least costly method of obtaining all single-phase power from the inverter is by means of a single autotransformer, connected line-to-line, with taps at appropriate points on the windings for either two-wire or three-wire output. Figure 6 shows the transformer-to-inverter connection to produce 120/240 volts, 400 Hz, single-phase power. Related test results are briefly summarized in the Appendix. The inner taps are used for 400 Hz operation; the outer taps are used for 60 Hz operation.

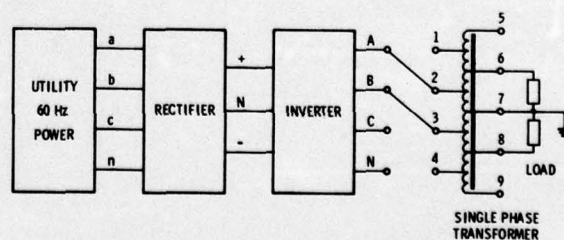


Figure 6. Connections for 400 Hz, Single-Phase, 120/240 V, Three-Wire Power

METHODS OF COMMUTATING STEP CURRENTS

Prior to this investigation the power rating of the original inverter circuit (Figure 3) was limited primarily by the current ratings of the step voltage commutation transistors. Breadboards capable of handling peak powers of 30 kVA have been built using transistor step commutation. However, to extend the inverter performance to the 100 kVA region, step circuits had to be developed in which the transistors were replaced by thyristors. To describe the change in design of step commutation, consider the following:

If the y and x step functions are extracted from the flat-topped, three-phase, line-to-neutral output voltages, they appear as shown in Figure 7a. These functions have a fundamental frequency three times that of the output voltages. The step widths and heights of the y and x functions are derived from computer-optimized, stepped waveforms.

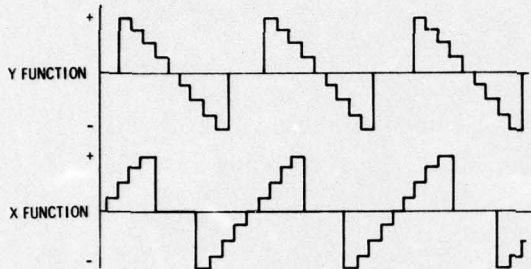


Figure 7a. Graphical Definitions of y and x Functions

Figure 7b shows a basic circuit for generating the y and x step voltage functions. When the transformer voltage polarity is positive, the y function switches start at step 4 and generate voltage steps sequentially down to the zero level and the x function switches start at the zero level and generate voltage steps sequentially up to step 4. When the transformer polarity is negative the y function switches start at the zero level and generate negative voltage steps to step 4 and the x function switches start at step 4 and generate negative voltage steps until the zero level is reached.

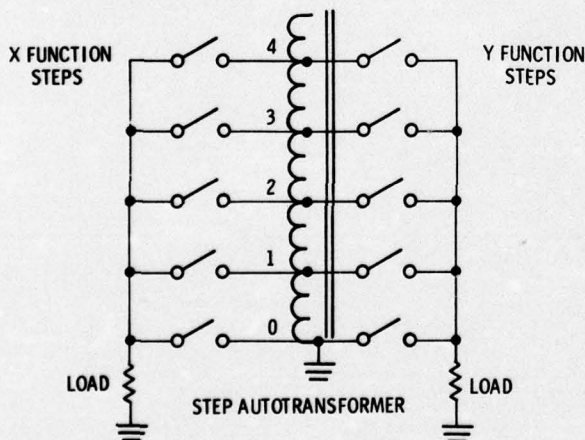


Figure 7b. Elementary Step Forming Circuit

Illustrated in Figure 8 is a step forming circuit that uses thyristors to change voltage levels, plus all possible combinations of voltage polarities and current flows for the y and x functions. Analysis

of thyristor commutation requirements for conditions 8a through 8h indicates that all required step changes can be achieved with two basic commutation schemes. Discussed below are methods for determining the appropriate commutation scheme for each y and x voltage step change situation and methods for configuring an improved step forming circuit.

Y Function

In Figure 8a, with voltage and current flow positive, it is desired to transfer current flow from SCR4 to SCR3 in accordance with the y waveform defined in Figure 7a. SCR3 is maintained biased off by the conduction of SCR4; therefore, an auxiliary circuit is required to commute SCR4.

In Figure 8b, with voltage positive and current flow negative, it is desired to transfer current flow from SCR4 to SCR3. Turning on SCR3 reverse biases and turns off SCR4, causing transfer of current flow to SCR3. Commutation of this type does not require auxiliary turn off circuits and will be referred to as "free commutation."

In Figure 8c, with voltage and current flow negative, it is desired to transfer current flow from SCR3 to SCR4. Turning on SCR4 reverse biases SCR3, resulting in free commutation. In Figure 8d, with voltage negative and current flow positive, an auxiliary commutation circuit is required to transfer current flow from SCR3 to SCR4.

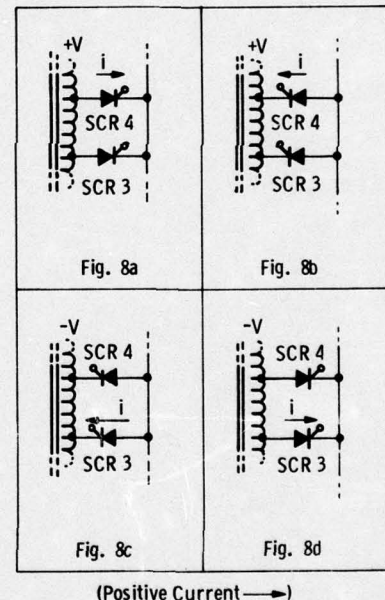


Figure 8. Basic Thyristor Step Forming Circuits

Y FUNCTION STEP TRANSFORMER VOLTAGE POLARITY	STEP VOLTAGE & CURRENT	
	IN-PHASE	OUT-OF-PHASE
+	AUX. COMM. REQUIRED	FREE COMMUTATION
-	FREE COMMUTATION	AUX. COMM. REQUIRED

Table II. Commutation Methods for Steps Formed by the y Function

X Function

A similar approach can be used for the x function, referring to Figures 8e through 8h. Tables II and III summarize commutation methods for all combinations of voltage polarities and current flow directions for the y and x functions, respectively. Through these tabulations, methods can be visualized for reorganizing the y and x step circuits to exploit the free commutation approach.

The original step circuit (Figure 9a) can be modified such that one half of the step thyristors are connected to a free commutation bus and the other half connected to an auxiliary commutation circuit (Figure 9b). The new step circuit improves system efficiency by eliminating four diodes and by setting up current paths that bypass the commutation transistors one-half the time. The schematic diagram in Figure 10 shows the improved step commutation incorporated into the inverter breadboard circuit.

The new step circuit is a continuation of the trend toward reducing the number of power semiconductors required to produce 5% total harmonic content, three-phase voltages. Figure 11, for example, shows that 72 power semiconductors (thyristors, diodes, and transistors) were required in 1969. As studies on the inverter progressed, the requirement steadily decreased to where only 28 will be used in 1974. This reduction is achievable by:

- Using reverse conducting thyristors in place of thyristor-bypass diode combinations.

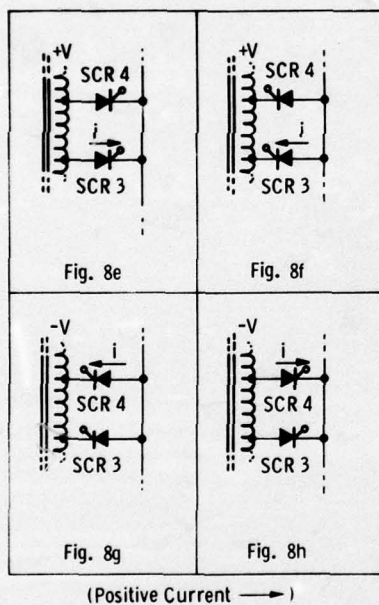


Figure 8 (Cont.). Basic Thyristor Step Forming Circuits

X FUNCTION STEP TRANSFORMER VOLTAGE POLARITY	STEP VOLTAGE & CURRENT	
	IN-PHASE	OUT-OF-PHASE
+	FREE COMMUTATION	AUX. COMM. REQUIRED
-	AUX. COMM. REQUIRED	FREE COMMUTATION

Table III. Commutation Methods for Steps Formed by the x Function

- Reducing the number of voltage steps on the autotransformer
- Phase shifting the inverter current so that zero current flows in the auxiliary commutation step circuits so that only free commutation is needed.

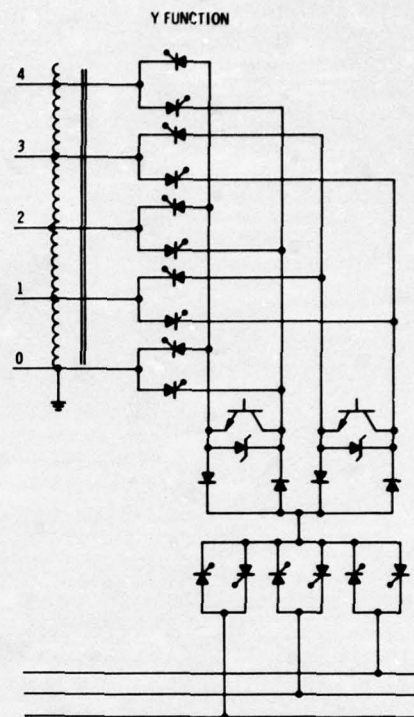


Figure 9a. Original Step Forming Circuit

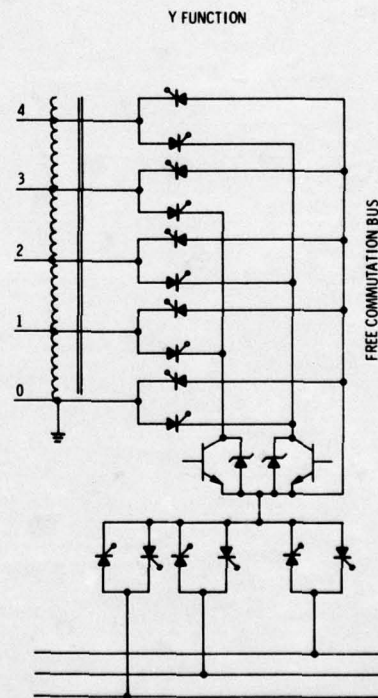


Figure 9b. Improved Step Forming Circuit

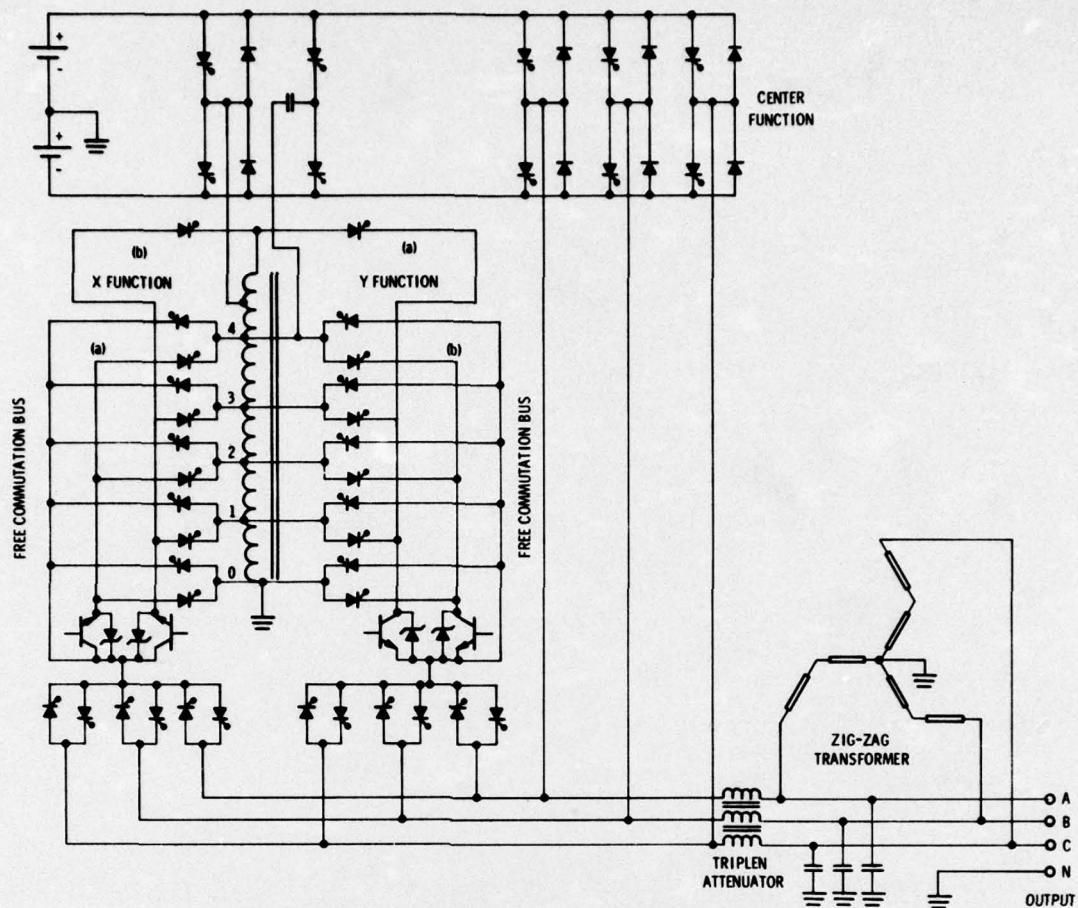


Figure 10. Improved 12.5 kVA Inverter Breadboard Circuit

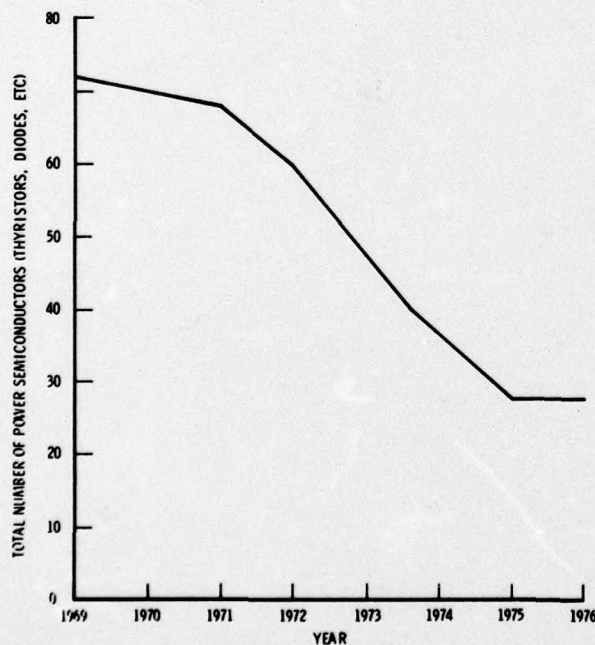


Figure 11. Number of Inverter Power Semiconductors Required to Produce Three-Phase

Elimination of the auxiliary commutation circuits and the associated step thyristors, as suggested in the third point, would account for 12 of the semiconductors eliminated. The penalty, however, is greater capacitance required at the inverter output. That is, at 400 Hz the circuit is cost effective, but at 60 Hz the cost of added capacitors exceeds that of the replaced thyristors. The waveform quality achievable with this circuit at 400 Hz three-phase, full load is shown in Figure 12. Total harmonic content for the illustrated waveform is 0.95%. Total harmonic content at no load is approximately 3%.



Figure 12. Output Voltage Produced by the Improved Circuit.

Table IV provides preliminary design estimates of size and weight for the inverters rated at 15 kVA for the MERDC-required combinations of frequencies, three-phase and single-phase operation. The efficiency of these inverters will exceed 90% for three-phase operation and 84% for single-phase operation.

POWER RATING	WEIGHT (LB)	VOLUME(FT ³)
15 KVA, 3 PHASE, 400 HZ	65	1
15 KVA, 3 PHASE, 400 or 60 HZ	100	2
15 KVA, 3 PHASE, 400 or 60 HZ OR 10 KVA, 1 PHASE, 400 or 60 HZ	150	3

Table IV. Preliminary Weight and Volume Estimates

REPLACING TRANSISTORS WITH THYRISTORS

Advantages of employing transistor starvation commutation of step thyristors, compared to typical thyristor commutation circuits, are that it requires virtually no energy storage in inductors or commutation capacitors, has low switching losses, and is capable of shorter voltage step widths (because of faster switching capability). Disadvantages are its power limitation (about 30 kVA), higher cost, and need for Zener diodes to provide transistor transient voltage protection. Starvation commutation is also difficult to achieve with high current transistors or parallel transistor combinations.

By reorganizing the step forming circuit it became possible to directly substitute a thyristor reverse voltage commutation circuit (Figure 13) for the transistor starvation commutation circuit.

This was followed by fabrication of experimental step circuits which demonstrated the possibility of achieving considerably higher inverter ratings. For 60 Hz inverters, step currents of 1,000 amperes — sufficient for a 100 kVA system — were commutated. Thus far, commutation of step currents of 300 amperes has been demonstrated for 400 Hz inverters.

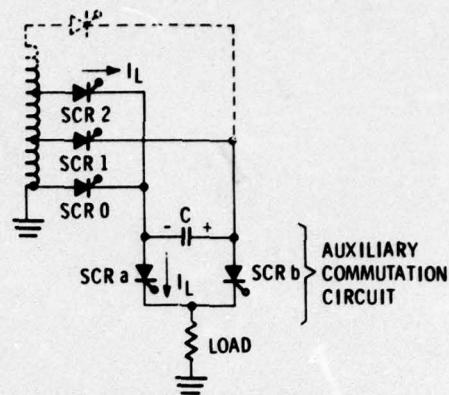


Figure 13. Step Changing Circuit Using Thyristor Reverse Voltage Commutation

Current is transferred from one voltage level to another by a two-step commutation sequence. Assume that in Figure 13 thyristors SCR2 and SCRa are conducting current to the load, that the transformer polarity is positive, and that capacitor C is charged as indicated. In order to transfer the load current to level 1, SCRb and SCR1 are gated on. The discharge of capacitor C reverse biases SCRa and turns it off. SCR 2 is turned off by the reverse voltage ring up of capacitor C which leaves it properly charged for the next step change to level 0. Load current continues to flow through SCR1 and SCRb.

SUMMARY

The Delco breadboard inverter is an example of the Army-sponsored development of dc link technology to obtain a family of compact, lightweight, and efficient power conditioners. Experiments have demonstrated the feasibility of extrapolating the present Delco technology to the 100 kVA level by replacing transistor commutation circuits with thyristors. Through use of innovative switching to obtain desired waveshapes, it is possible to significantly reduce componentry and circuit complexity and improve reliability.

APPENDIX

SINGLE PHASE PERFORMANCE SUMMARY FOR MERDC 12.5 kVA, THREE-PHASE BREADBOARD INVERTER

ITEM	PERFORMANCE		
Voltage output	120 Vrms, single-phase, 2-wire, 60 Hz or 400 Hz 120/240 Vrms, single-phase, 3-wire, 60 Hz or 400 Hz Adjustable between 95 and 105% of rated voltage.		
Power Output	10 kW, 0.8 PF lagging; 200% rated current for 5 seconds at 400 Hz. 10 kW, 0.8 PF at 60 Hz. (Input - output filter designs limited performance below 200% rated current. Further development required.)		
Voltage Waveform	Total harmonic content: 2.1% at 400 Hz, single-phase 4.3% at 60 Hz, single-phase DC voltage component: less than 10 mV.		
Single-Phase Efficiency	Frequency (Hz)	Load	Efficiency (%)
	60	10 kW, 0.8 PF, 2-wire	89
	60	10 kW, 0.8 PF, 3-wire	90
	400	10 kW, 0.8 PF, 2-wire	84
	400	10 kW, 0.8 PF, 3-wire	85
Effect of Unbalanced Load (Single-Phase, 3-wire)	0.8% at 400 Hz for 5.8 kW unbalance 2.2% at 60 Hz for 5.8 kW unbalance		
Voltage Regulation	Less than 1% for all load conditions at 60 Hz or 400 Hz.		
Voltage Modulation	Less than 3 volts		
Transient Voltage Performance (Single Phase)	<p>With the inverter system initially operating at no load, rated voltage, and at 400 Hz, the rms terminal voltage dropped to 80% of rated voltage when a 0.4 PF lagging load having an impedance of 0.5 per unit was applied to the output terminals of the set. The output voltage jumped to 120% rated voltage when the load was removed. Test not conducted at 60 Hz.</p> <p>With the system operating at 400 Hz and rated voltage, a step change in load from no load to 10 kW, 0.8 PF caused the output voltage to drop to 81% of rated voltage. Removal of the load caused the output voltage to jump to 118% of rated voltage. (See Figure 14a.).</p> <p>Under the same conditions as above but with the inverter operating at 60 Hz, the output voltage dropped to 70% rated value when the load was applied, and increased to 130% when the load was removed. (See Figure 14b.)</p>		

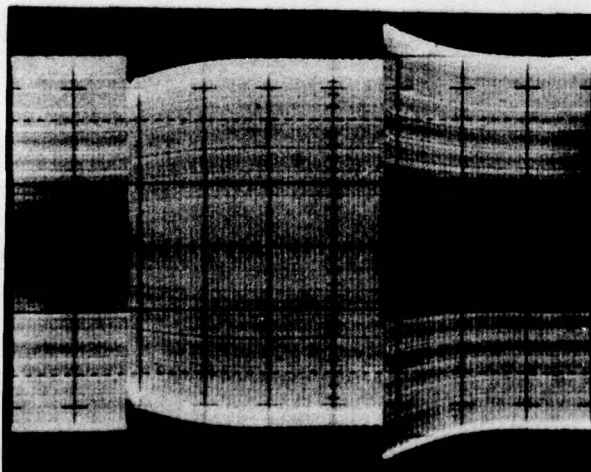


Figure 14a. Single-Phase, 400 Hz, No Load-Full Load Voltage Transients

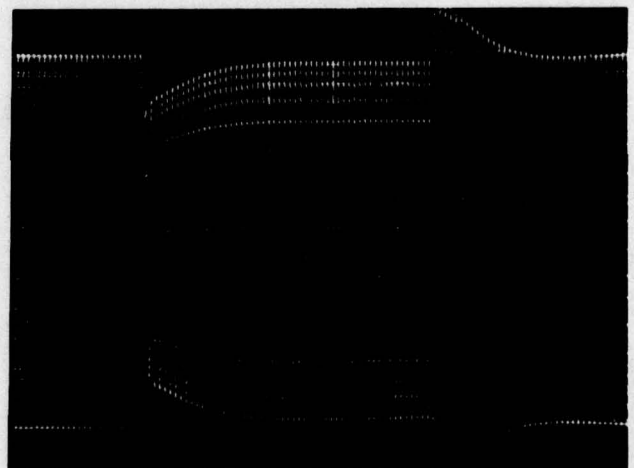


Figure 14b. Single-Phase, 60 Hz, No Load-Full Load Voltage Transients

15KVA INVERTER

PARTS LIST

CDRL ITEM A002

ITEM NO. 0006

CONTRACT NO. DAAK02-72-C-0210

MATERIAL MEMORY TIMING CIRCUIT 110° WIDE
PACIFIC CENTER

ITEM	PART NUMBER AND DESCRIPTION		QTY
	DESCRIBE IN DETAIL		
	PART NO., VENDOR CODE, SPECIFICATION, DIMENSION, UNIT, TRADE OR BRAND NAME, COLOR, TYPE OF MATERIAL, ETC.		
1	LM375N		3
2	DM8520		2
3	SN74123		3
4	SN7492		2
5	SN7400		1
6	SN7107		2
7	SN7493		3
8	HPR0M1-8256-5		5
9	10K OHM RESISTOR 1/4WATT		7
10	330 OHM RESISTOR 1/4WATT		1
11	470 OHM RESISTOR 1/4WATT		1
12	.01 M F CAPACITOR		5
13	38uH INDUCTOR		1
14	5 PF CAPACITOR		1
15	56 PF CAPACITOR		1
16	75 PF CAPACITOR		1
17	220 PF CAPACITOR		6
18	1000 PF		1
19	120 PF		2
20	4200 PF		1
	TOTAL		

MATERIAL R.F. DRIVERS

ITEM	PART NUMBER AND DESCRIPTION		QTY
	DESCRIBE IN DETAIL		
	PART NO., VENDOR CODE, SPECIFICATION, DIMENSION, UNIT, TRADE OR BRAND NAME, COLOR, TYPE OF MATERIAL, ETC.		
1	CIRCUIT BOARD RSK 2CZ96-501		6
2	SN5402N QUAD NOR GATE		18
3	SN5413N DUAL NAND SCHMITT TRIGGER		6
4	HT1-6500-5 HARRIS QUAD CORE DRIVER		6
5	F625-92-06 CORE, INDIANA GENERAL		36
6	2N5333 TRANSISTOR PNP		12
7	RESISTOR, 50 OHM $\pm 3\%$ DALE NH-5		12
8	RESISTOR, 39 OHM $\pm 5\%$ 1W.		12
9	ZENER DIODE, U2 740 40VOLT		6
10	CAPACITOR, MYLAR 0.015 MFD 100VDC		6
11	CAPACITOR, TANTALUM, 100 MFD, 10VDC		6
12	DIODE, 1N4448		72
13	HEAT SINK TX 0506-13		12
14	CONNECTOR, ELCO P/N 00-6007-044-980-002		6
15	T-STRUT VECTOR TS169N		6
16	RETAINER KIT, VECTOR BZ 19H		4
17	CASE GUIDE VECTOR BZ 19-6-1 3.5"		5
	TOTAL		

MATERIAL

TH-12120202 R.F. DRIVE ISOLATION CIRCUIT

	PART NUMBER AND DESCRIPTION		
	DESCRIBE IN DETAIL PART NO., VENDOR CODE, SPECIFICATION, DIMENSION, UNIT, TRADE OR BRAND NAME, COLOR, TYPE OF MATERIAL, ETC.		
ITEM		QTY	
	SINGLE SCR DRIVE (1A REQUIRED)		
1	DIODE 1N4448	4	
2	TRANSFORMER, DELCO XT-71036	1	
3	CIRCUIT BOARD	1	
4	TERMINAL, USE CO. 12PIC	4	
	PARALLEL SCR DRIVE (14 REQUIRED)		
1	DIODE 1N4448	8	
2	TRANSFORMER, DELCO XT-72029	1	
3	CIRCUIT BOARD	1	
4	TERMINAL USE CO. 12PIC	6	
	TOTAL		

MATERIAL POWER SWITCH ASSEMBLY ITEM NO. 0006

ITEM	PART NUMBER AND DESCRIPTION	QTY	
	DESCRIBE IN DETAIL		
	PART NO., VENDOR CODE, SPECIFICATION, DIMENSION, UNIT, TRADE OR BRAND NAME, COLOR, TYPE OF MATERIAL, ETC.		
1	THYRISTOR 82-2022 INTERNATIONAL RECTIFIER	20	
2	DIODE 82-0060 INTERNATIONAL RECTIFIER	2	
3	CAPACITOR 0.1MFD SPRAGUE 196P1099654	18	
4	RESISTOR 200HM 25WATT $\pm 3\%$ DALE NH-25	18	
5	CAPACITOR 20MFD CORNELL-DUBILIER SCR6-105	1	
6	CAPACITOR 10MFD SPRAGUE 3301231	3	
7	TRANSFORMER, STEP XT74004	1	
8	TRANSFORMER, ZIG-ZAG XT77034	1	
9	TRANSFORMER, C.T. COMBINATION 57, 1T 965-55/51-A2-2	3	
10	TRANSFORMER, SINGLE PHASE XT-73030	1	
11	INDUCTOR TRIPLEX XL72028	1	
12	INDUCTOR TRIPLEX XL73014	1	
13	INDUCTOR 5.5 MICROMH	1	
14	INDUCTOR 5 MICROMH	1	
15	CIRCUIT BREAKER 65 AMP HENNINGSEN P3XAM1516	1	
16	WIRE, #12 TEFLON FLEXIBLE MIL-W-16878D TYPE E	100 FT	
17	WIRE, #14 TEFLON FLEXIBLE MIL-W-16878D TYPE E	50 FT	
18	FAN ROTARY MARK 4 GRILL SERIES 747	4	
19	TERMINAL SPACER 5903-4-16	3	
20	TERMINAL SPACER 5903-6-8	1	
21	TERMINAL PAIR CAT. NO. 320574	50	

MATERIAL STEP COMMUTATION CIRCUIT 60HZ

	PART NUMBER AND DESCRIPTION		
	DESCRIBE IN DETAIL		
ITEM	PART NO., VENDOR CODE, SPECIFICATION, DIMENSION, UNIT, TRADE OR BRAND NAME, COLOR, TYPE OF MATERIAL, ETC.	QTY	
1	THYRISTOR 82-2072 INTERNATIONAL RECTIFIER	3	
2	CAPACITOR 20MFD 5% TOL 333P12	4	
3	TRANSFORMER TB	2	
4	INDUCTOR L1	2	
5	INDUCTOR L2	1	
6	POWER SUPPLY 66VDC 9 AMPS	1	
7	CAPACITOR 125MFD G.E. 28F1104FC	2	
	TOTAL		

MATERIAL

AUXILIARY POWER SUPPLY

[illegible]

15KVA INVERTER

PARTS LIST

CDRL ITEM A002

ITEM NO. 0006

CONTRACT NO. DAAK02-72-C-0210



AD-A035 045

FREQUENCY CONVERTER PORTABLE ALTERNATING CURRENT
MULTIFREQUENCY 10 KW VOL. (U) GENERAL MOTORS CORP
GOLETA CALIF DELCO ELECTRONICS DIV T CORRY JAN 75
R75-3 DAAK02-72-C-0210 F/G 9/5

4/4

UNCLASSIFIED

NL

FILED	SUPPLEMENTARY	END
		DATE
		FILMED
		6-8
	INFORMATION	

EMENTARY

RMATION

Beh
missing